Using Spatially Explicit Data and Modeling to Inform Ecological Risk Assessment at Mining Sites

Brad Parks[1], Sean Kosinski[2], Les Williams[2] and Andrew Nicholson[2]

1. *Integral Consulting, Chile*
2. *Integral Consulting, USA*

ABSTRACT

The ecological effects of mine development are typically assessed using very conservative assumptions inherent in screening level ecological risk assessments (SLERAs) vis-à-vis toxicity and exposure estimates. We recommend a simple efficient SLERA followed by a focused population-level risk assessment designed by risk assessors in consultation with mine planners and geochemists. We provide an example of an evaluation of potential risk using spatially explicit modeled data and empirical site data for multiple media including soil and expected future sediment and surface water conditions at a mining site. These data were used in conjunction with an expanded list of toxicity values and exposure pathway models to evaluate risks to ecological receptors at the site. Results indicate a handful of chemicals of potential concern based on exceedances of low-effect criteria for bats, barn swallow, and spotted sandpiper. In an effort to focus risk management, a third-tier risk assessment was conducted using an individual-based model (IBM) to evaluate uncertainties in the risk assessment approach and characterize population-level impacts for the bat *Myotis* spp. as an example species. This population modeling effort expands upon the exposure scenarios and anticipated future site habitats used to evaluate both baseline risks and potential mitigation of risks by overlaying material to reduce exposure to areas with higher levels of chemicals of interest. The results demonstrate the usefulness of population modeling tools in assessing future exposure scenarios to meet risk management objectives in the real-world currency of natural resources (i.e., population abundance) as opposed to the pass/fail hazard-quotient paradigm currently utilized in risk assessment. This study also illustrates the importance, even at a screening level, of a robust, spatially explicit site-specific data set in understanding future conditions and site management alternatives.

INTRODUCTION

Ecological risk assessment (ERA) is a process for evaluating the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors. Typically, ecological risk assessments use toxicological, ecological, and geochemical information to evaluate risk of impacts to wildlife and habitats from human activities such as chemical spills, resource extraction, and land conversion. If ecological risks are unavoidable, the ERA process can help identify opportunities to minimize or mitigate these risks (USEPA, 1998). This process at the lowest-tier consists of utilizing maximum exposure concentrations to ecological receptors which not surprisingly results in overly conservative risk estimates. At the second-tier, ecological risk assessors can utilize detailed spatially explicit site date including analysis of the mine activities, mine geochemistry, habitat formation, habitat access, and contributions of the pit lake water quality, sediment quality, and wall rock concentrations in evaluating ecological risk. A third-tier assessment involves investigating population-level effects for those ecological species which exhibited risk based upon the spatially-informed assessment (i.e., second-tier). This evaluation utilizes population models or population viability analyses built upon the body of scientific literature describing life history characteristics for the receptor of interest. A subset of these models, individual-based models (IBMs) allow the risk assessor to incorporate ecosystem complexities such as physiological factors, intra- and inter-specific interactions, resource availability, habitat structure, and abiotic factors. Ultimately, the results from IBMs provide a refined assessment with a potential range of risk outcomes in ecosystem metrics that are potentially simpler to conceptualize than the hazard quotient construct. These metrics include population abundance, extinction or quasi-extinction risk, and population growth rates relative to a control condition (i.e., no stressor in the system).

As an example of this three-tiered ERA approach, we present the results of an ERA which was conducted to evaluate a proposed expansion of the Twin Creeks Mine in the arid Great Basin ecosystem of northern Nevada, USA. State and federal permitting requires an evaluation of ecological risk associated with mining activities. In the case of proposed pit mine expansion, several spatial and temporal issues complicate the ERA approach. The assessment must be conducted for an ecosystem (a pit lake) that does not yet exist, using predictions of what hydrologic, chemical, and biological conditions are likely to be present several decades into the future as the lake infills. The ERA needs to account for spatial heterogeneity of chemicals to evaluate chemicals that animals will be exposed to once the pit lake exists. The risk assessment also needs to incorporate site geochemistry, which influences the bioavailability of metals and other chemicals to which wildlife may be exposed (Flynn *et al.*, 2003; Suedel *et al.*, 2006). These issues call for spatially and temporally explicit approaches in order to accurately predict risk and, if risks of adverse effects are found, inform the approach to reduce or mitigate these risks. The uncertainty associated with the dynamic lake condition offers another benefit to the three-tiered assessment approach whereby incorporating temporal and spatial variability in exposure profiles into a probabilistic population modeling scenario to further inform risk management.

METHODS

A screening-level ecological risk assessment was conducted, consistent with regulatory guidance (USEPA, 1997; USEPA, 1999; USEPA, 2001), which uses maximum concentrations of chemicals in the proposed pit vicinity, assumes complete bioavailability, and compares chemical data to conservative toxicological criteria. The conservatism of this approach resulted in a long list of metals that may cause risk, with substantial uncertainty about the realism of these risks under future conditions.

To address these uncertainties, a spatially explicit ERA was then conducted as a second-tier assessment. This approach incorporated an expanded set of modeled and empirical data over multiple time scenarios to evaluate expected future sediment and surface water conditions, including:

- Spatially explicit data sets were used to evaluate what concentrations of metals might be expected at the pit wall surface to which the ecological community could be exposed (Figure 1). This effort included detailed characterization of the vertical extent of concentrations throughout the geologic section (Figure 2).
- Estimates of pit lake surface water elevation and water quality was modeled over the complete 200 years of lake infill by other workers (Itasca, 2010; Geomega, 2010).
- A conceptual site model was designed to look at how ecological communities of the lake might be expected to develop after pit closure and infill (Figure 3).

These data sets and conceptual models were used to inform a site-specific wildlife exposure model. The model creates estimates of exposure to local wildlife that might be expected to colonize or forage in the habitats that develop as the pit lake is created and habitat is formed (Figure 4). These estimates of exposure were evaluated relative to toxicological criteria for concentrations of metals that have been shown in the scientific literature to cause no or low levels of adverse effects to wildlife exposed to these metals.

Based on the risk outcomes from the second-tier ERA, a third-tier assessment was conducted to illustrate the usefulness of population models for an example receptor which exceeded the low-effect criteria. We developed an IBM which accounts for the reality that individual organisms are distributed in a non-uniform way and may respond differently to identical environmental conditions depending on sex, age, and health. Hexsim is a publically available modeling software developed for the purpose of analyzing individuals within an ecosystem over time by layering prey, habitat preferences, and movement patterns in a probabilistic manner (Heinrichs *et al.*, 2010). The model is individual-based, spatially-explicit through user-defined spatial data which capture landscape structure, habitat quality, and stressor distribution, and trait-based through user-definitions such as age, sex, and fitness (Figure 4). The model was run using annual time-steps over the first 50 years of pit lake infill. Incorporating best-case and worst-case behavioral traits for the receptor species allows us to evaluate uncertainty in the evaluation. The results of this analysis allow us to compare population-level endpoints (i.e., abundance, population growth rate) over varying modeled assumptions and assist in gauging the environmental reality of presumed risks following the second-tier.

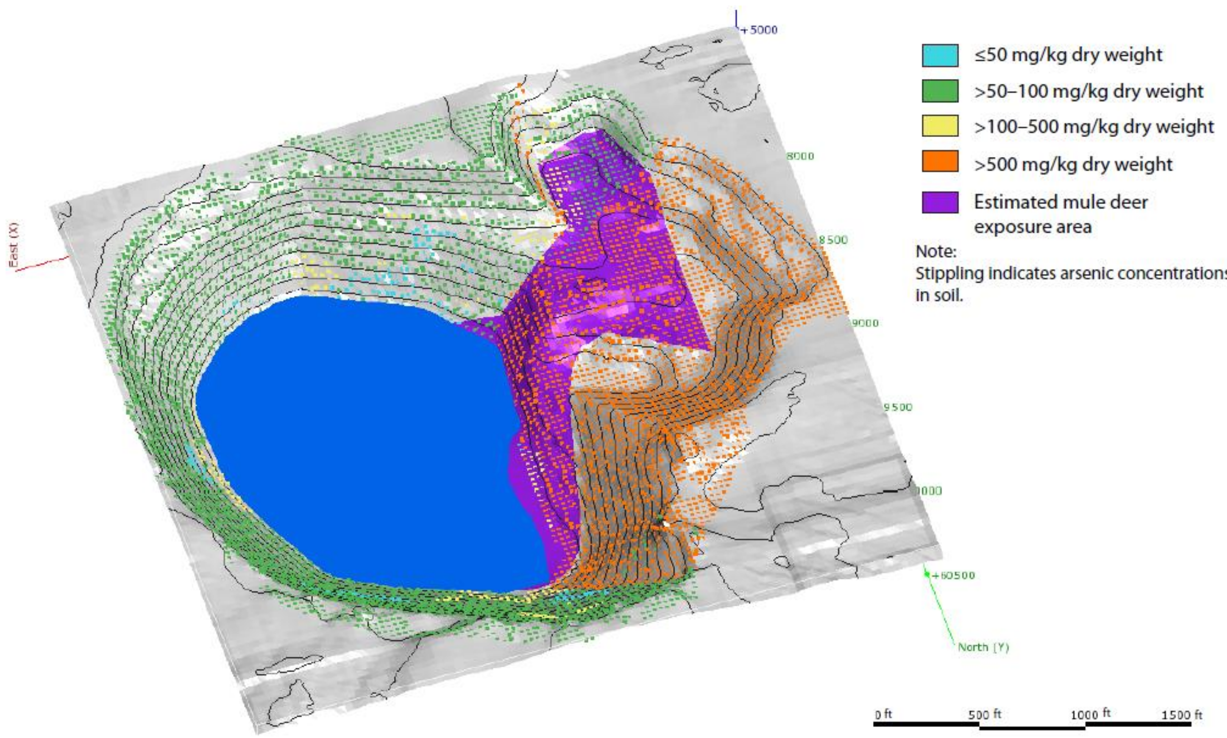

Figure 1 Predicted pit-lake geometry and arsenic distribution in the Vista Pit.

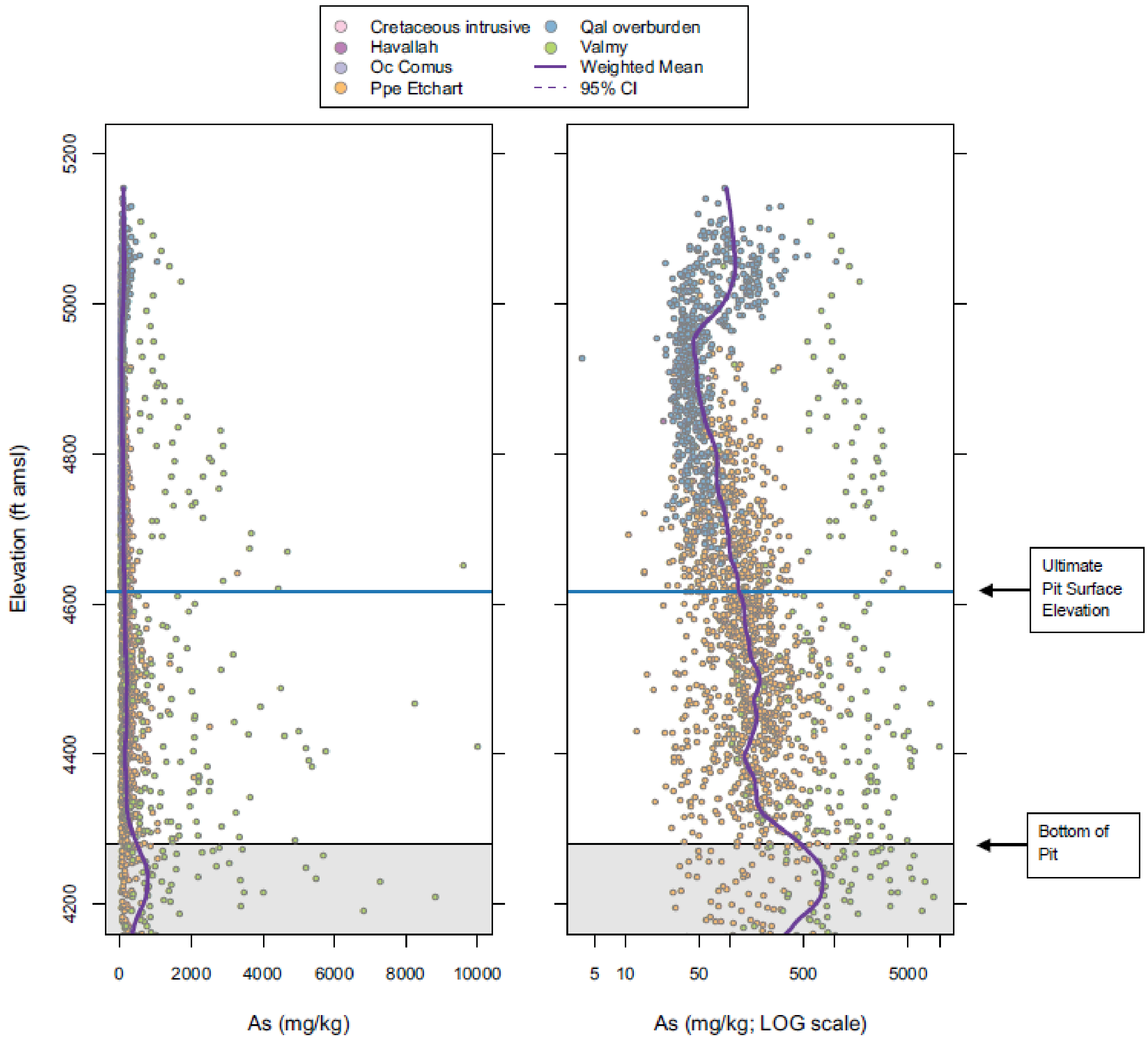

Figure 2 Arsenic concentrations as a function of depth in the proposed Vista Pit.

RESULTS AND DISCUSSION

Results of the wildlife exposure model included:

- No risks were predicted to modeled granivorous birds or ducks from exposure to chemicals at the site (Table 1).
- Low risks were predicted to ungulates, which could be redressed by considering pit wall mitigation. Exposures to antimony and arsenic were greater than the no-effect criteria for these metals if mule deer were conservatively assumed to spend all their time at the site. This risk could be eliminated if overburden (surficial materials removed prior to mining) is applied to the areas of the pit most likely to be frequented by grazing ungulates (Figure 2).
- A handful of metals were retained as chemicals of potential concern that exceeded low-effect criteria for one or more taxa of invertivorous mammals and birds (Table 1). However, there are important aspects of the model and the site conditions that are likely to reduce these risks:

- Predictions of risk were largely related to necessarily simplifying assumptions in the model of uptake factors from foods to consumers. When applied to bioaccumulation of metals, these factors often overestimate uptake, particularly at higher concentrations (Drexler *et al*., 2003).
- The model assumes complete bioavailability of these metals; however, geochemical modeling indicates that at this site, several metals are likely to be in valence states or composite forms that reduce their bioavailability. For example, surface water pH greater than 5 is likely for this site, which would maintain aluminum in insoluble form, substantially limiting bioavailability of this chemical.

The availability of littoral habitat is likely to play a major role in shaping the ecological community of the site. Rapid infill rates over the first 20 years or so is likely to preclude the development of littoral habitat and will lead to the formation of a deep, mesotrophic pit lake. As lake infill slows, littoral habitat development will be regulated by the spatial proximity of shallow lake waters to horizontal pit wall benches that could allow for the development of a shallow vegetated photic zone. Low organic matter content in this arid ecosystem is likely to slow and limit shoreline soil capable of supporting substantial vegetation, further limiting habitat development.

CONCLUSIONS

The use of spatially and temporally explicit geochemical and ecological modeling to inform risk assessment has substantively improved our understanding of the ecological trajectory and potential for risk at the future Vista Pit lake. In an effort to further refine the risk characterization and weight-of-evidence for risk management alternatives, a third-tier assessment involving population model projections for receptor species of interest was conducted. Following closure and infill from groundwater, Vista Pit is likely to function as a deep, mesotrophic pit lake. The development of shallow littoral habitat capable of supporting wildlife will depend on the intersection of pit geometry and final surface level equilibrium, is likely to be prevented during initial rapid infill rates, and will be limited in the long term by low rates of organic matter accumulation in this arid ecosystem. Most chemicals that were evaluated were not found to be present at concentrations that suggest the potential for adverse effects on wildlife. Steps such as the use of overburden to cover pit wall surfaces that present a high likelihood of exposure may also be helpful in mitigating risk.

ACKNOWLEDGEMENTS

This work was funded and sponsored by Newmont Mining Corporation through subcontract to Enviroscientists, Inc.

REFERENCES

Drexler, J., N. Fisher, G. Henningsen, R. Lanno, J. McGeer, and K. Sappington. 2003. Issue paper on the bioavailability and bioaccumulation of metals. Submitted to: U.S. Environmental Protection Agency, Risk Assessment Forum, Washington D.C.

Flynn, H.C., A.A. Meharg, P.K. Bowyer, and G.I. Paton. 2003. Antimony bioavailability in mine soils. *Environmental Pollution*, Vol.124 No.1.

Geomega. 2010. Vista VII Pit Lake Chemogenesis. Final Draft. Prepared for Newmont Mining Corporation, Carlin, NV. September 9, 2010.

Heinrichs, J., D. Bender, D. Gummer, and N. Schumaker. 2010. Assessing critical habitat: evaluating the relative contribution of habitats to population persistence. *Biological Conservation*. 143: 2229-2237.

Itasca. 2010. Appendix D: Predictions of Vista Phase 7 lake infilling. 2010 Update of Twin Creeks numerical groundwater flow model and simulations for Vista Phase 7 Pit. Memorandum submitted to Newmont Mining Corporation. Lakewood, CO. Itasca Denver Inc. August 5, 2010.

Suedel, B., A. Nicholson, C. Day, and J. Spicer. 2006. The value of metals bioavailability and speciation information for ecological risk assessment in arid soils. *IEAM 4*(2):355-364.

USEPA. 1997. Ecological risk assessment guidance for Superfund: Process for designing and conducting ecological risk assessments. EPA 540-R-97-006. Interim final. U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington D.C.

USEPA. 1998. Guidelines for ecological risk assessment. EPA 630-R-95-002F. U.S. Environmental Protection Agency, Washington D.C.

USEPA. 1999. Screening Level Ecological Risk Assessment Protocol for Hazardous Waste Combustion Facilities Peer Review Draft. Appendix C: Media-to-receptor bioconcentration factors (BCFs).

USEPA. 2001. The role of screening-level risk assessments and refining contaminants of concern in baseline ecological risk assessments. ECO Update Intermittent Bulletin. EPA 540/F-01/014. U.S. Environmental Protection Agency, Washington D.C.

Table 1. Summary of toxicological criteria exceedances[a] using the wildlife ingestion model.

Receptor:	Chukar	Mule Deer	Myotis	Barn Swallow	Mallard	Spotted Sandpiper
Feeding guild:	Granivore	Browsing Ungulate	Aerial Invertivore	Aerial Invertivore	Omnivore	Shoreline Invertivore
Aluminum	—	—	X	X[b]	—	X
Antimony	—	X[b]	X[c]	No criteria	No criteria	No criteria
Arsenic	—	X[b]	X[b,c]	—	—	X[c]
Barium	—	—	—	—	—	—
Beryllium	—	—	—	No criteria	No criteria	No criteria
Cadmium	—	—	—	—	—	—
Chromium	—	—	X[b,c]	X[b,c]	—	X[b,c]
Copper	—	—	X[b,c]	X[b]	—	X [b]
Iron	—	—	—	—	—	—
Lead	—	—	—	X[b,c]	—	X [b]
Manganese	—	—	—	—	—	—
Mercury	—	—	—	X	—	X
Nickel	—	—	—	—	—	—
Selenium	—	—	X[b]	X[b]	—	X[b,c]
Silver	—	—	—	—	—	—
Zinc	—	—	—	—	—	—

Notes:
— = Criteria not exceeded.
X = Criterion exceeded
[a] Exposures at three time scenarios: 50 years of lake infill, 100, and 200 years were run and all results are summarized here.
[b] Criterion for lowest observed adverse effect is not exceeded, indicating risk is low
[c] For one or more time scenarios, concentration does not exceed criterion.

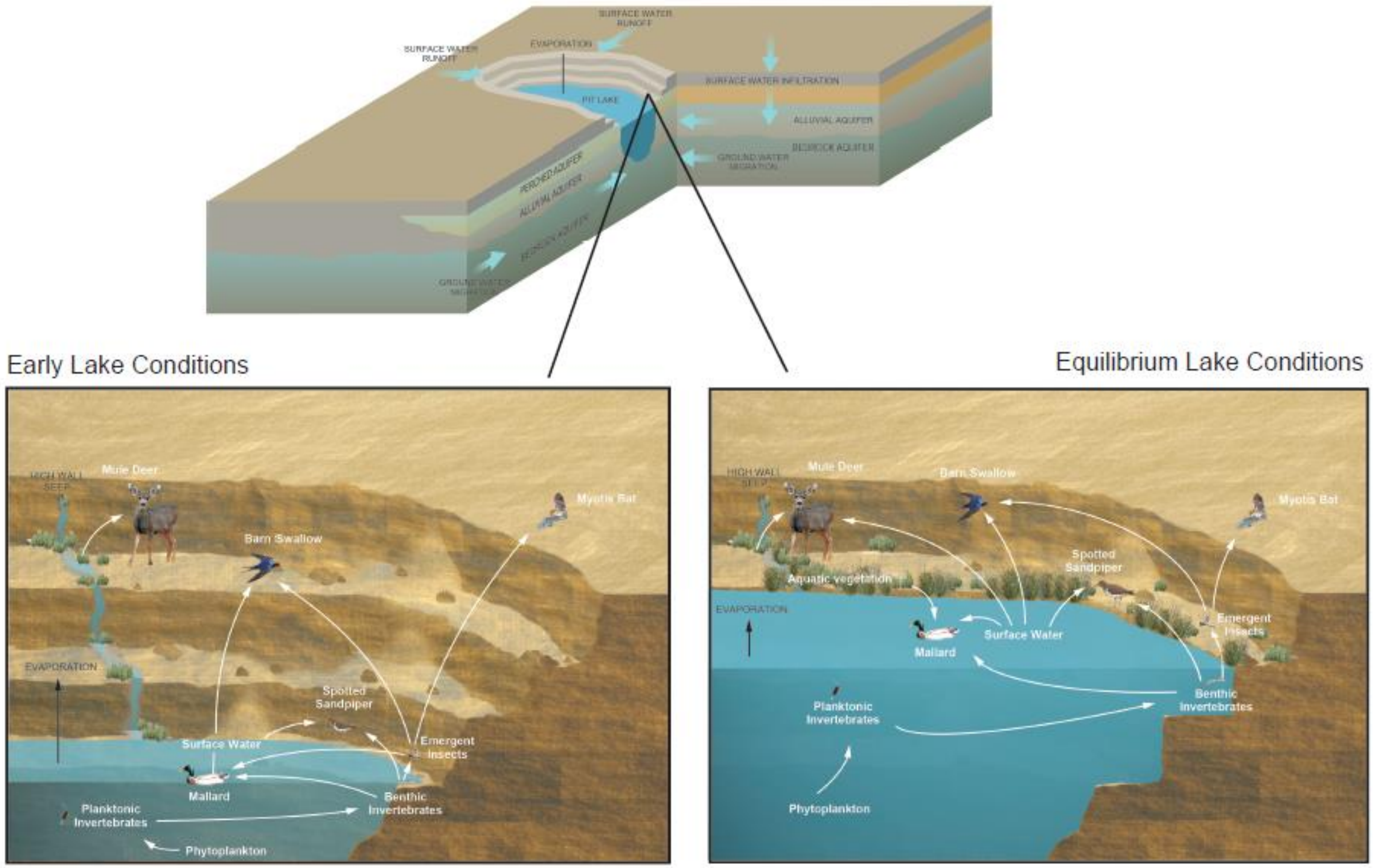

Figure 3 Ecological conceptual model of pit infilling and habitat development.

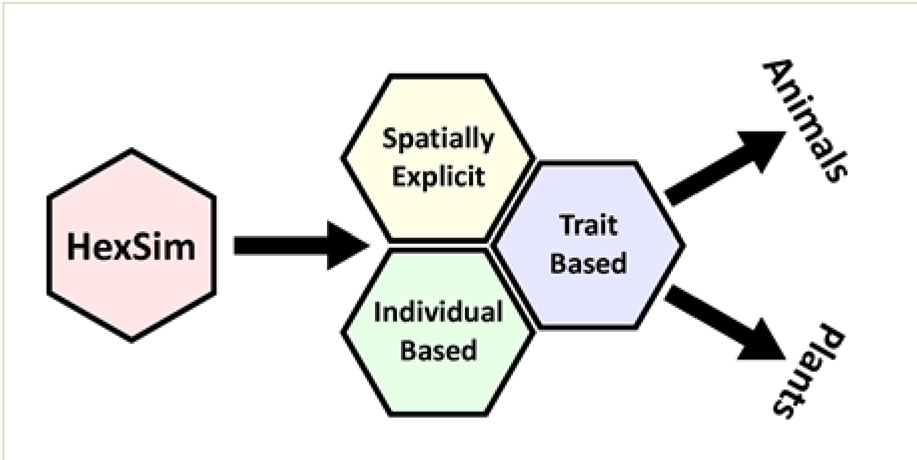

Figure 4 Simplified modeling diagram depicting HexSim individual-based model structure.