Hydrology-Related Research Projects at NatCap

Below is a list of research topics and projects that NatCap staff have identified as having potential to advancing modeling practice in water-based ecosystem services. They vary in level of effort and knowledge required, from graduate student independent studies, to opportunities to engage in coordinated research efforts among NatCap and collaborating modeling teams to produce high-level journal publications. Interested parties should contact Perrine Hamel (perrine.hamel@stanford.edu) to discuss opportunities to coordinate and/or collaborate.

InVEST Annual Water Yield Model

P1.1 Characterize the relationship between landscape characteristics and empirical parameters used in the InVEST Annual water yield model (or similar Budyko-type models)

Background: The InVEST annual water yield model provides a first-order estimate of the effect of land use on water yield based on the well-known Budyko hydrological framework. Although the Budyko approach has been in use for a long time, it is still unclear how to identify the eco-hydrological parameters of the model, Z or ω (cf. Tallis et al., 2014; Hamel & Guswa, 2014).

Proposed research: This project would aim to synthesize the literature relating landscape characteristics to eco-hydrological parameters used in the Budyko approach (e.g. Donohue et al., 2012; Xu et al., 2013; Zhang et al., 2008). The outcomes will be published in the InVEST documentation to better support the application of the annual water yield model to ungauged catchments. Findings from this work may also be published in a peer-reviewed journal given the ongoing interest in the Budyko approach in the hydrologic community.

P1.2 Test the performance of the InVEST Annual water yield model in a tropical catchment

Background: The annual water yield model provides a first-order estimate of the effect of land use on water yield. So far, testing of the model performance has been limited in scope and restricted to temperate and semi-arid climates. Additional case studies are needed to help refine the understanding of model's strengths and limitations. This project can draw on the work conducted by Hamel and Guswa (2014), with hydrological data coming from a current NatCap project or an external database.

Proposed research: The proposed scope of work includes:

- Sensitivity analyses of the InVEST annual water yield model
- Analysis of the model performance for predictions of land use change over time or space (regional study)
- Comparison with process-based models (such as SWAT, RHESSys), or global models (such as WaterWorld, WaterGAP)

InVEST Sediment Retention Model

P2.1 Characterize the response of the new sediment retention model to land use change

Background: The InVEST sediment retention model was recently redeveloped to improve the representation of land use change and facilitate model uncertainty assessment. The model is now based on an index of hydrologic connectivity that has been developed by Borselli et al. (2008; Vigiak et al., 2012). Although the model has been shown to provide a reasonable first-order estimate of sediment yield in temperate and subtropical catchments, questions remain about the model sensitivity to key parameters, e.g. catchment topography, grid resolution, or riparian zone characteristics.

Proposed Research: The scope of this project includes:

- Comparison of the distribution of the index of connectivity obtained for different landscapes
- Analysis of the model predictions for synthetic landscapes (investigating changes in slope, grid resolution, land use/cover in the riparian zone)

P2.2 Develop the hydrological parameter database for sediment models

Background: The InVEST sediment retention model requires as inputs empirical coefficients representing the retention process from typical land use and land covers (also known as the C and P factors of the Universal Soil Loss Equation). Over the years, NatCap has built a database of studies to help model users select these parameters. However, this database has not been studied or kept up to date

Proposed Research: This work would update the database with any recently identified values in the literature, and also involve analysis of the updated database to identify regional trends. The project includes a short review of the literature on sediment transport modeling, and a meta-analysis of global values of sediment cover and practice factors (USLE C and P values).

InVEST Nutrient Retention Model

P3.1 Develop the hydrological parameter database for the nutrient model

Background: Similar to the InVEST sediment retention model, the nutrient model requires as inputs empirical coefficients representing the retention process from typical land use and land covers. Over the years, NatCap has built a database of studies to help model users select these parameters.

Proposed Research: This database needs to be updated and analyzed for regional trends. This project includes a short literature review of the nutrient transport dynamics, and a meta-analysis of global values of the surface and subsurface nutrient retention efficiencies.

InVEST Seasonal Water Yield Model (In Development)

P4.1 Parameter selection for the Seasonal water yield rainfall-runoff model

Background: The InVEST Seasonal water yield model is currently in development. The model will provide a useful addition to the InVEST suite of tools by allowing users to assess and value seasonal water provisioning services. One component of the seasonal model relies on a lumped rainfall-runoff model developed by Zhang et al. (2008), which comprises five parameters. Preliminary sensitivity analyses have been conducted but additional analyses are needed to refine the default parameter selection procedure.

Proposed research: The proposed scope of work includes:

- Continuing the sensitivity analyses for the five parameters in different climates (e.g. temperate, arid, semi-arid, tropical)
- Assessing the current guidance for parameter selection by comparing model predictions to observations
- Conducting a regression analysis to examine the relationships between calibrated parameters and catchment characteristics using a dataset of calibrated parameters and catchment characteristics (Zhang et al., 2008)

P4.2 Develop and test the Seasonal water yield index model

Background: The InVEST Seasonal water yield model is currently in development. The model comprises a rainfall-runoff module described in project P4.1 above. The second component of the model is a seasonal topographic index used to distribute the water provisioning service spatially. This index draws on the current literature on the use of topographic indices to represent hydrologic connectivity (Lane et al., 2004; Agnew et al., 2006; Qiu, 2009), providing qualitative information on the spatial distribution of zones of high and low recharge. Additional analyses are needed to interpret the model quantitatively.

Proposed research: This work requires good GIS analysis skills and will rely on data from current NatCap projects. The proposed scope of work includes:

- Comparison of the seasonal recharge index distribution obtained for different landscapes
- Analysis of the model predictions for synthetic landscapes (investigating changes in slope, grid resolution, land use/cover distribution)
- Comparison of the model outputs with process-based models such as SWAT and RHESSys.

P4.3 Develop and analyze the database on land use change effect on seasonal water yield

Background: A typical application of the InVEST Seasonal water yield model is to predict the effect of land use change on the seasonal water yield. For example, InVEST users may need information on the effect of forest conversion during the dry season. Given the large knowledge gaps that remain in hydrological science, a literature review has been conducted at NatCap to synthesize the empirical evidence supporting the main hydrological theories on land use

change. A database of studies has been compiled, which can be queried for regional information on the magnitude of the water yield response to land use change, as a function of catchment physiographic characteristics.

Propose research: Further work is needed to i) complete the database of studies, and ii) conduct regressions and meta-analyses to derive quantitative estimates of the effect of land use change on seasonal water yield. This work will complete the model documentation and may be published in a peer-reviewed journal given the current interest in land use change predictions outside the NatCap community.

Reservoir Storage Yield and Reliability

P5.1 Develop guidance for characterizing the service impacts of changing reservoir storage capacity

Background: Many applications of the InVEST sediment retention model involve concern over sediment deposition into water bodies. In particular, sediment retention in reservoirs reduces the useful life and immediate buffering capacity of the reservoir. However, the precise effect on the benefits of lost storage capacity are a function both of inflow characteristics, as well as the uses for which the reservoir is maintained, and the relative priority given to those different uses (eg, hydropower production, flood control, irrigation, and recreation).

Proposed research: NatCap has identified a subset of the literature (as examples, see Xie *et al* 2013 and Lee *et al* 2011) that can serve as a starting point for understanding the service impacts of changes in reservoir yield. The proposed work would build off this literature and additional review of the relevant hydrology and water management literature to develop practical guidance for identifying the impact of reduced reservoir capacity on reservoir service provision. This would include specification of appropriate metrics and guidance for how to estimate the impact of storage reduction on those metrics (eg, reliability of yield for hydropower production, percentage time water levels meet recreational requirements, flood mitigation potential conditional on inflow characteristics).

References

Agnew, L.J., Lyon, S., Gérard-Marchant, P., Collins, V.B., Lembo, A.J., Steenhuis, T.S. & Walter, M.T. (2006). Identifying hydrologically sensitive areas: bridging the gap between science and application. *Journal of environmental management*. [Online]. 78 (1). p.pp. 63–76. Available from: http://www.ncbi.nlm.nih.gov/pubmed/16169658. [Accessed: 24 January 2014].

Borselli, L., Cassi, P. & Torri, D. (2008). Prolegomena to sediment and flow connectivity in the landscape: A GIS and field numerical assessment. *Catena*. 75 (3). p.pp. 268–277.

Donohue, R.J., Roderick, M.L. & McVicar, T.R. (2012). Roots , storms and soil pores : Incorporating key ecohydrological processes into Budyko's hydrological model. *Journal of Hydrology*. 436-437. p.pp. 35–50.

Hamel, P. & Guswa, A.J. (2014). Uncertainty analysis of a spatially-explicit annual water-balance model: case study of the Cape Fear catchment, NC. *Hydrology and Earth System Sciences Discussions*. [Online]. 11 (10). p.pp. 11001–11036. Available from: http://www.hydrol-earth-syst-sci-discuss.net/11/11001/2014/hessd-11-11001-2014.html. [Accessed: 6 October 2014].

Lane, S.N., Brookes, C.J., Kirkby, M.J. & Holden, J. (2004). A network-index-based version of TOPMODEL for use with high-resolution digital topographic data. *Hydrological Processes*. [Online]. 18 (1). p.pp. 191–201. Available from: http://doi.wiley.com/10.1002/hyp.5208. [Accessed: 5 May 2014].

Lee, Y., Yoon T. and Shah. F. (2011) Economics of integrated watershed management in the presence of a dam. *Water Resources Research* 47 (10). Available from: http://onlinelibrary.wiley.com/doi/10.1029/2010WR009172/full

Qiu, Z. (2009). Assessing Critical Source Areas in Watersheds for Conservation Buffer Planning and Riparian Restoration. *Environmental Management*. p.pp. 968–980.

Tallis, H.T., Ricketts, T., Guerry, A.D., Wood, S.A., Sharp, R., Nelson, E., Ennaanay, D., Wolny, S., Olwero, N., Vigerstol, K., Pennington, D., Mendoza, G., Aukema, J., Foster, J., Forrest, J., Cameron, D., Arkema, K., Lonsdorf, E., Kennedy, C., Verutes, G., Kim, C.K., Guannel, G., Papenfus, M., Toft, J., Marsik, M., Bernhardt, J., Griffin, R., Glowinski, K., Chaumont, N., Perelman, A., Lacayo, M., Mandle, L., Hamel, P. & Chaplin-Kramer, R. (2014). *InVEST 3.0 User's Guide. Available at: http://ncp-dev.stanford.edu/~dataportal/invest-releases/documentation/current_release/ [accessed June 2014]*. [Online]. Available from: http://ncp-dev.stanford.edu/~dataportal/invest-releases/documentation/current_release/.

Vigiak, O., Borselli, L., Newham, L.T.H., Mcinnes, J. & Roberts, A.M. (2012). Comparison of conceptual landscape metrics to define hillslope-scale sediment delivery ratio. *Geomorphology*. 138 (1). p.pp. 74–88.

Xie, J., Wu, B, and Annandale, G. (2013). Rapid Reservoir Storage-Based Benefit Calculations. Journal of Water Resource Planning and Management, 139 (6) pp712-722. Available online at: http://ascelibrary.org/doi/abs/10.1061/(ASCE)WR.1943-5452.0000312

Xu, X., Liu, W., Scanlon, B.R., Zhang, L. & Pan, M. (2013). Local and global factors controlling water-energy balances within the Budyko framework. *Geophysical Research Letters*. 40 (23). p.pp. 6123–6129.

Zhang, L., Potter, N., Hickel, K., Zhang, Y. & Shao, Q. (2008). Water balance modeling over variable time scales based on the Budyko framework – Model development and testing. *Journal of Hydrology*. 360 (1-4). p.pp. 117–131.