Abstract No: A-081

THE IMPACT OF LAND COVER CHANGE ON THE HYDRAULIC CONDUCTIVITY IN TROPICAL PEATLANDS

Sofyan Kurnianto[1*], James T. Peterson[2], John Selker[3], J. Boone Kauffman[1] and Daniel Murdiyarso[4]

[1]*Dept. of Fisheries and Wildlife, Oregon State University, USA*
[2]*US Geological Survey, Oregon Cooperative Fish and Wildlife Research Unit, Department of Fisheries and Wildlife, Oregon State University, USA*
[3]*Biological and Ecological Engineering Dept., Oregon State University, USA*
[4]*Center for International Forestry Research, Indonesia*

**Corresponding author: Sofyan.Kurnianto@oregonstate.edu; kurnians@oregonstate.edu*

SUMMARY

Hydraulic conductivity is one of the most important parameters that describe peat properties related to water movement through the peat profile. In the application of peat hydrology, the information about saturated hydraulic conductivity is required to estimate the amount of water needed to maintain the saturation condition in the peat dome and is also required to simulate the peat water table depth and groundwater flow. However, some uncertainties regarding hydraulic conductivity in the tropical peatlands especially those related to the effect of peat swamp forest conversion on hydraulic conductivity remain. Hydraulic conductivity was estimated at four different land cover types in West Kalimantan, Indonesia. We utilized the slug test method to estimate the hydraulic conductivity at three depths (1.0, 3.5, and 6.0 m) and interpreted the data based on the Bouwer and Rice (1976) approach. In total, 324 wells were installed in 21 sites including five sites in shrubs, five sites in oil palm plantations and eight sites in forests and three sites in recently burnt forest with six replications for each site. The results show that forested peatlands have higher conductivity with an average of 0.63 ± 0.36 m d^{-1} (mean ± s.e.) compare with oil palm of 0.20 ± 0.13 m d^{-1} and shrubs of 0.16 ± 0.08 m d^{-1}.
The relationship between hydraulic conductivity land cover types, measurement depth and peat properties such as carbon concentration, loss on ignition, bulk density, and degree of decomposition, were assessed using hierarchical linear models. Results depicted that hydraulic conductivity was likely be the best explained by the measurement depth, bulk density, and forests-non forests land cover. However, carbon concentration and loss on ignition provided a very small portion for explaining the variability of hydraulic conductivity.

Keywords: *hydroecology, permeability, forest conversion, eco-hydrology, peat properties*

INTRODUCTION

Hydraulic conductivity is an important parameter that describes the ability of water to flow through a soil profile. In the application of peat hydrology, information about saturated hydraulic conductivity is required to estimate the amount of water needed to maintain the saturation condition in the peat dome (Dommain *et al.*, 2010). Hydraulic conductivity is a characteristic parameter required to simulate the depth of water table in tropical peatlands *(Wösten et al.*, 2006). Kelly *et al.* (2014) suggested that the saturated hydraulic conductivity in tropical Peruvian peatlands varied among different types of peat in minerotrophic and ombrotrophic systems. However, few studies have examined how the hydraulic conductivity of peatland varies with land cover types. In addition, the relationship between peat properties, degree of decomposition, and saturated hydraulic condition remain unclear. Therefore, we estimated the saturated hydraulic conductivity at different land cover types to address the following research questions:

1. What is the effect of the land cover on the saturated hydraulic conductivity?
2. What are the relationships between peat properties and hydraulic conductivity?
3. Do the relationships between peat properties and the hydraulic conductivity differ with land cover?
4. What is the distribution of hydraulic conductivity within the peat column?

We hypothesize that hydraulic conductivity in forests is higher than other land cover types because forested peat is less disturbed due to the human activities. Therefore, peat forest would have lower bulk density and more porosity than any land cover types and eventually higher hydraulic conductivity compare to peat underlain other land cover types. To answer these questions, we used hierarchical linear models to statistically evaluate the relationship between hydraulic conductivity, land cover, peat properties, and their interaction. Outputs from these models including the estimated model coefficients and measures of uncertainty that can be used to assess the relative importance of peat properties and land cover types on saturated hydraulic conductivity.

METHODS

Research design

The field research was conducted in Ketapang, West Kalimantan, Indonesia that could be classified as the coastal peatland because its distance to the coast is less than 20 km. To assess the effect of land cover type on the saturated hydraulic conductivity (later identified as K_s), measurements were performed in 21 sites across four different land cover types comprising eight sites in forests, three sites in recently burnt forests, five sites in shrubs, and another fives sites oil palm plantation.

At each site, a 120 m long transect was installed with six plots set at 30 m intervals. Wells were established at each plot within a circle of 2-m diameter along a line that was perpendicular to the transect and K_s was measured at three depths: 1.0, 3.5, and 6.0 m. If the peat depth in a plot was less than 6.0 m, the deepest measurement was taken above the mineral layer. For shrub and oil palm plantation sites, transects were set perpendicular to drainage canals with the first plot set 20 m away from the canals.

To study the influence of the peat properties on K_s, peat samples were collected for each plot and depth where K_s was measured. The peat samples, then, were transferred to the soil laboratory of Bogor Agricultural University for peat analysis, such as carbon concentration (C), bulk density (BD), and loss on ignition (LOI). The degree of humification was determined in the field qualitatively following the Von-Post method.

Data analysis

K_s calculation

The saturated hydraulic conductivity, K_s was analyzed with the Bouwer and Rice (1976) method using

$$K_s = \frac{r_c^2 \ln\left({R_e}/{r_w}\right)}{2L}\frac{1}{t}\ln\frac{H_0}{H_w},$$

where H_o is the initial head change and H_w is the head change over time. Since K_s, r_c, R_e, r_w, and L are constant, the value of $\frac{1}{t}\ln\frac{H_o}{H_w}$ should be constant and can be estimated by fitting a straight line in a plot of the relationship between time, t, and log (H_w/H_0). The term $\ln\left({R_e}/{r_w}\right)$ was calculated as:

$$\ln\left({R_e}/{r_w}\right) = \left(\frac{1.1}{\ln\left({H}/{r_w}\right)} + \frac{A + B.\ln\left({(m-L)}/{r_w}\right)}{{(L-d)}/{r_w}}\right)^{-1}$$

and in the case of a well fully penetrating an aquifer, $\ln\left({R_e}/{r_w}\right)$ was determined using

$$ln\left({R_e}/{r_w}\right) = \left(\frac{1.1}{ln\left({H}/{r_w}\right)} + \frac{C}{{(L-d)}/{r_w}}\right)^{-1},$$

where A, B, and C were dimensionless values based on the chart governed by Bouwer and Rice (1976).

Statistical model

We initially evaluated the relationship between peat properties and land cover types on the tropical peatland K_s by using linear regression models. However, the K_s measurements were taken in 21 sites in which six plots were nested within each site and three K_s measurements were made at different depths in each plot. Because the measurements at a site or plot were potentially dependent, we examined residuals from the preliminary analyses and found strong site-level dependence. To account for the spatial dependence related to sites and plots within sites, we use hierarchical linear models (Bryk and Raudenbush 2002) to evaluate the factors related to K_s.

We use a systematic approach to evaluate the relationship between land cover and peat properties on the K_s. Prior to analyses, land cover was coded as a binary variable (0 and 1) for each type and depth predictors were standardized to a mean of zero and standard deviation of one to facilitate model fitting. We then developed a global model that contained all of the variables potentially related to K_s including: C, BD, LOI, measurement depth, and land cover type and used it to determine the random effects that best accounted for the spatial dependence. To do this, we use the global model and evaluated different combination of random effects that included intercept and slopes that varied normally among sites and among plots nested within sites. The model with the best approximating random effects was considered that with the lowest Akaike Information Criteria (AIC; Akaike 1973) with the small-sample bias adjustment (AICc; Hurvich and Tsai 1989). We then used these random effects to identify the factors that best explained variation in K_s. by fitting all possible combinations of predictors (21 models). The relative plausibility of each model was estimated by calculating AICc and model weights using the procedures detailed in

Burnham and Anderson (2002). All of the statistical analysis in this study was performed by using R software with the MuMIn package (Barton, 2015) for the AIC analysis.

RESULTS AND DISCUSSION

K_s varied greatly both within and among sites. It ranged from about 0.001 to 10 m/d (Figure 1). The high variability of K_s was observed at all of the sites. The outliers, points located outside of the boxplots tails, also occurred consistently at all of sites. The skewness of K_s, however, was slightly different among land cover types in which forests tended to have right skewness, whereas K_s in oil palm plantations and shrubs skewed to left.

The best approximating random effects for explaining spatial dependence included an intercept and slope for measurement depth that varied among sites. The most plausible hierarchical model for predicting K_s contained the measurement depth, forests land cover, and the interaction between depth and forests land cover. This model was similar to next the best approximating K_s model that contained LOI. Using the model weights and the 1/8 criteria suggested by Royall (1977) for evaluating strength of evidence, only two additional candidate models were considered plausible models for predict K_s and they contained BD, and C as the explanatory variables.

The model selection criterion indicated that the most-likely model to explain variation in K_s did not contain the peat properties. Rather, variation in K_s was best explained by position within the peat column and whether the land cover was forest or non-forest. Saturated hydraulic conductivity was negatively related to depth of measurement indicating K_s decreased downward within a peat column. The random effects also indicated that average K_s and the relationship between K_s and depth varied among sites suggesting a strong spatial component to the relationship. The forest main effect accounted for 14% of the variation in average K_s among sites and the interaction between depth and forest accounted for 12% of this variation. This interaction also was negative, indicating that the effect of land cover decreased with depth. However, the random effects also indicated that there was substantial variability in K_s that could not be explained by the components in the best model.

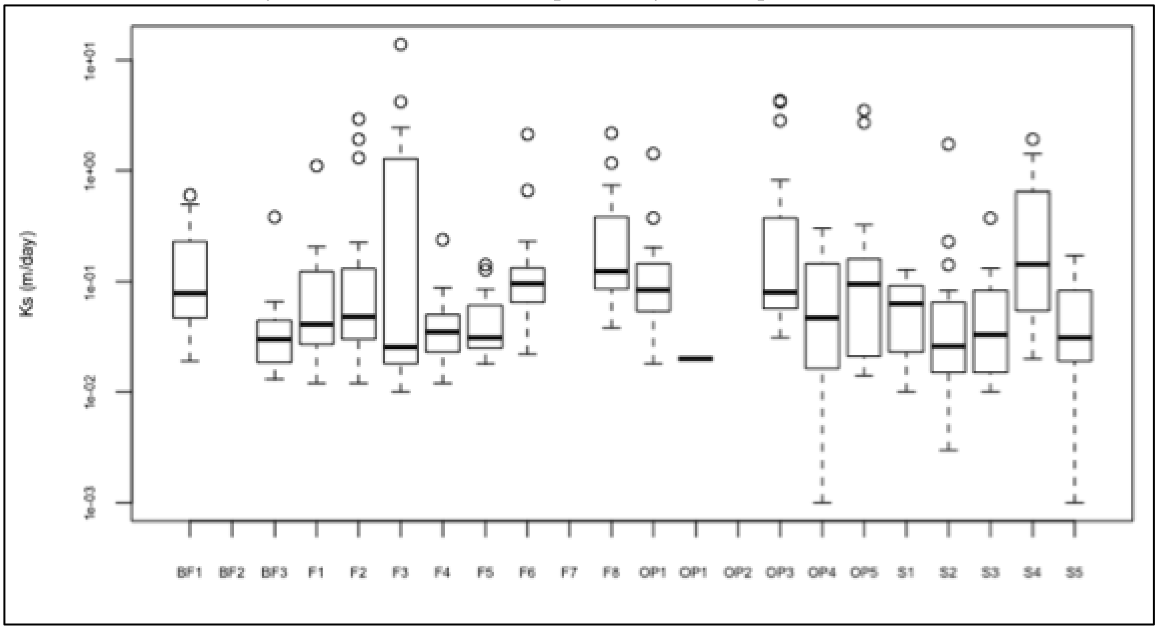

Figure 1: The K_s distribution for each site.

Model selection criteria also indicated that bulk density was a plausible explanation for variation in K_s within and almond sites. Bulk density was, on average, negatively related to Ks. However, the relationship varied greatly among sites and confidence limits for the parameter estimates included zero indicating a lack of precision of the estimate. Model selection criteria also indicated little to no evidence that K_s was related to other properties of peat, LOI and C, which was further supported by very small effect sizes (slopes), i.e., 0.009 and 0.001.

A hierarchical model containing depth of measurement, forests land cover, the depth and forests land cover interaction, and bulk density was also tested to assess the sensitivity of model estimates to the changes in the coefficients. By varying the bulk density and depth coefficients -50% to 50%, the response of K_s depicted the different patterns. The changes in K_s were greater for the peat with higher bulk density. Conversely, in the lower bulk density, the model coefficient perturbation was not really affected hydraulic conductivity. For the depth coefficient, K_s measured close to the surface were more sensitive to changes in the model coefficient than in the deeper peat (Figure 2).

CONCLUSION

The study shows that there was a substantial variability in K_s both within and among sites. The hierarchical model could be used to evaluate the relationship between the peat properties, land cover types and vertical distribution of saturated hydraulic conductivity by incorporating the nested measurement design implemented in this study. In general, hydraulic conductivity was decreased vertically from the peat surface to the deeper position. Forest conversion to other land cover types was likely reduced the peat hydraulic conductivity. However, the relationship among peat properties and hydraulic conductivity was weaker presumably due to the large variability within sites and plots. The parameters in the best approximating model also were unable to account for this predictable spatial variation even when models included all of the predictor variables.

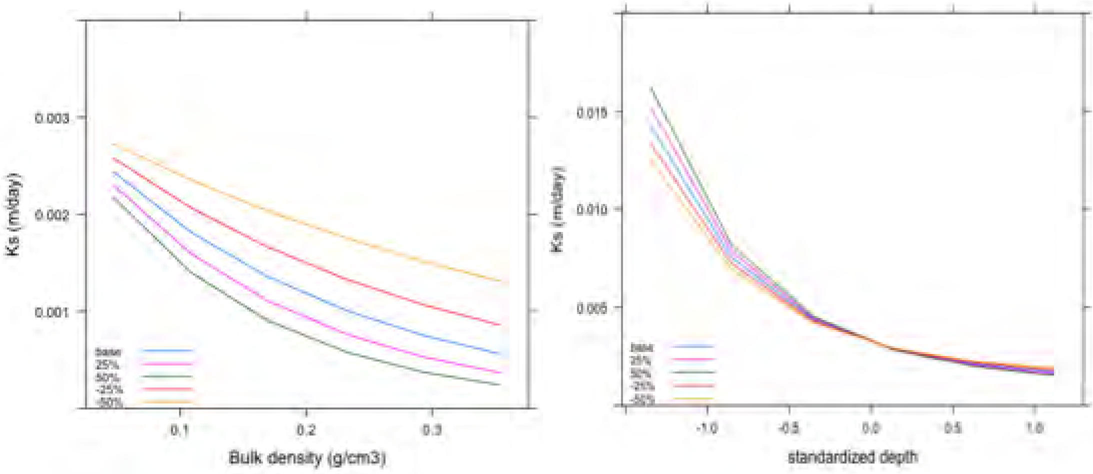

*Figure 2: Plots of the relationship between saturated hydraulic conductivity and bulk density (left) and depth (right) using the equation of log (Ks) = -2.514 – 0.084Depth + 0.17Forest -2.076BD – 0.607Depth*Forest for each varying bulk density coefficient (left) and depth coefficient (right) while keeping the remaining coefficient at the average value.*

ACKNOWLEDGMENTS

The study was supported by the funding from the United States Agency for International Development under the project Kalimantan Wetlands and Climate Studies (KWACs). Part of this study was also funded by Sustainable Wetlands Adaptation and Mitigation Program (SWAMP).

REFERENCES

1. Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle. *Pages* 267-281 *In* Second International Symposium on Information Theory. B.N. Petrov and F. Csaki, *editors*. Akademiai Kiado, Budapest, Hungary.
2. Barton, K. 2015, ‗Package MuMIN'. http://cran.r-project.org/web/packages/MuMIn/index.html
3. Bouwer H, Rice R (1976) A slug test for determining hydraulic conductivity of unconfined aquifers.pdf. *Water Resource Research*, **12**, 423–428.
4. Bryk, A. S., and S. W. Raudenbush. 2002. Hierarchical linear models: applications and data analysis methods, 2nd edition. Sage, Newbury Park, California.
5. Burnham, K. P., and D. R. Anderson. 2002. Model selection and inference: an information-theoretic approach. Springer-Verlag, New York.
6. Dommain R, Couwenberg J, Joosten H (2010) Hydrological self-regulation of domed peatlands in south-east Asia and consequences for conservation and restoration. *Mires and Peat, Article*, **6**, 1–17.
7. Kelly TJ, Baird AJ, Roucoux KH, Baker TR, Honorio Coronado EN, Ríos M, Lawson IT (2014) The high hydraulic conductivity of three wooded tropical peat swamps in northeast Peru: measurements and implications for hydrological function. *Hydrological Processes*, **28**, 3373–3387.
8. Hurvich, C. M., and C. Tsai. 1989. Regression and time series model selection in small samples. Biometrika 76:297-307.
9. Royall, R.M. 1997. Statistical evidence: a likelihood paradigm. Chapman and Hall, New York.
10. Wösten H, Hooijer A, Siderius C, Rais DS, Idris A, Rieley J (2006) Tropical Peatland water management modelling of the Air Hitam Laut catchment in Indonesia. *International Journal of River Basin Management*, **4**, 233–244.