Lee MacDonald

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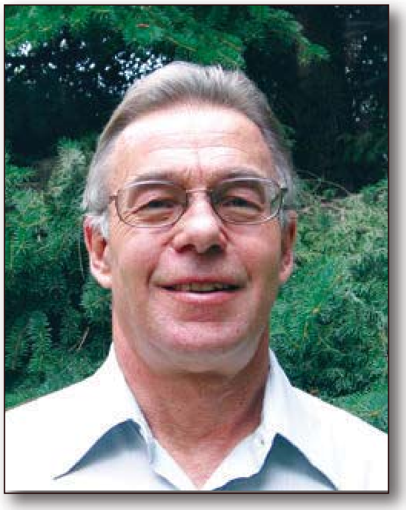
Dr. Lee MacDonald, a professor of Watershed Science, is retiring from active teaching after 22 years at CSU, a post-doctoral appointment at the University of Washington, and more than five years setting up research and training programs in developing countries. We've asked him to summarize lessons learned over his career.



Lessons Learned After 30 Years in Watershed Science

We don't teach hydrology, we teach physics. The basic principles of hydrology are relatively well known: 1) water runs downhill, 2) inputs equal outputs plus the change in storage, and 3) flowing water flows faster as it gets deeper. These are all just applications of basic physics, once one understands the underlying principles. Often water is going up in direction, such as when it evaporates from the soil or a plant, but this is downhill in energy terms because the atmosphere has such a strong pull on liquid water (vapor pressure deficit).

Obeying the second principle ("continuity equation") is critical to any hydrologic analysis, as water generally can't be created or destroyed. So inputs (usually precipitation) have to be balanced by the outputs (usually runoff, evapotranspiration, and any change in storage). Similarly, energy has to be conserved, so water flows faster when it is deeper, because there is less resistance along the bed and banks. Understanding and following these basic principles is the heart of hydrology. Knowing that hydrology is physics makes the basic principles easier to understand and apply.

The basic principles are easy, but the application is hard! The first principle is that water flows downhill, but predicting the direction and amount of flow requires information on the amount of energy that water has in different places, and the resistance to flow. So to predict evaporation we have to know how tightly water is held in the soil, air temperature and humidity, how much energy is available, and turbulence at the water-atmosphere interface. To determine the water balance, we have to accurately measure the different components of the water balance, but it is impossible to accurately measure precipitation, evapotranspiration, runoff, and water storage on large plots, much less an entire watershed (Figure 1).

Figure 1. *Most precipitation gages do not measure snow very accurately.*
Courtesy of Wendy Ryan, Fort Collins weather station

Spend time in the field, and learn from that. Hydrology is a data-based science, yet almost all of our education is conducted indoors. Without a field component, people are too prone to believe that hydrologic data are perfectly precise (to a computer, 10 cubic feet per second is 10.0000….), models accurately represent the underlying processes, and we can accurately characterize the variability in time and space. Students need to spend time in the field making measurements in order to appreciate the uncertainty in the underlying

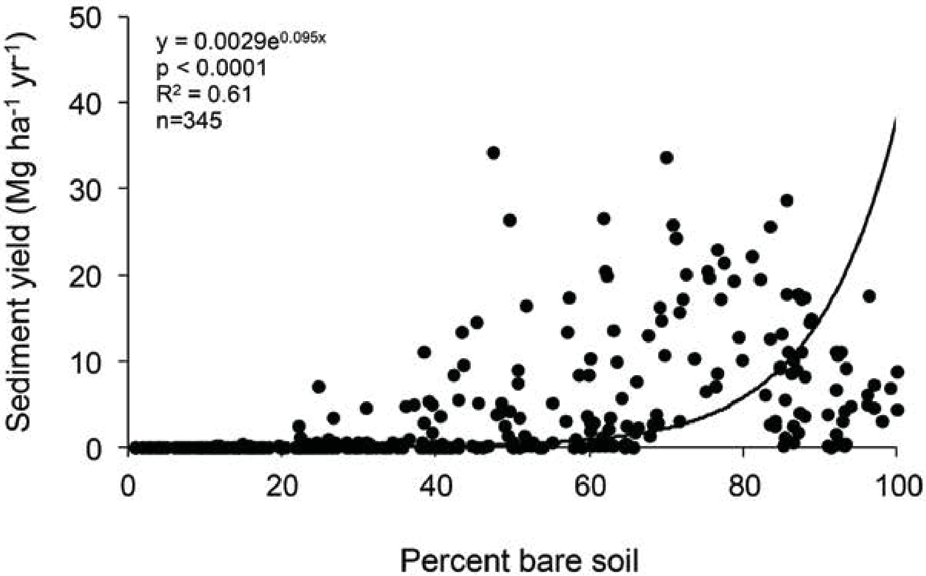


Figure 2. *Sediment yield versus percent bare soil for burned and unburned hillslopes in the Colorado Front Range (Larsen et al., 2009).*

data, and better understand the controlling processes (c.f., MacDonald, 1993). Teaching field-based courses is expensive in terms of equipment and time, but essential to the advancement of the science (NRC, 1991). Only by spending time in the field can we appreciate the differences between the reality in the field and the simplified approximations of our models, and the uncertainties in the data that underlie hydrologic science and our predictions.

Recognize the uncertainty, and watch your significant figures! The difficulties of measuring water movement and storage, when combined with the variability in time and space, means that our measurements are only approximations. Hence most of our hydrologic data are only accurate to within 1-30 percent, and many measurements, such as infiltration, have much lower accuracy at larger scales due to the tremendous variability in time and space. This has important implications for the accuracy of our models and predictions, and two significant figures are all we can reasonably report!

Climate change is creating even more uncertainty. When I started teaching in 1990, I taught climate change as a hypothesis that needed to be tested. With another 22 years of data, the warming trends in the lower atmosphere and oceans, and the rise in sea levels, are uncontestable. The warmer atmosphere and oceans are changing water movement and hence the amount and type of precipitation, Arctic ice cover, and evapotranspiration rates. These changes have tremendous effects both locally and globally ("teleconnections"), and we no longer can simply extrapolate from the past in order to project the future (e.g., Milly et al., 2008). The result is even more uncertainty in our models and predictions! The trends and persistence of the human-induced changes in the atmosphere and oceans is my biggest fear with respect to the future of humanity and our blue planet.

Hydrology and watershed management are both a science and an art. We know the basic principles of hydrology, but have trouble applying these in the field because of the uncertainties in the magnitudes of the underlying processes, the interactions between processes, and how the relative importance of different processes change under different conditions (e.g., the nonlinear increases in surface runoff with increasing rainfall intensity and soil moisture). Given our imperfect knowledge and measurements, we inevitably must estimate certain components, and then use our judgment to evaluate the accuracy of model structure, model parameters, and model results. This judgment is a learned art that comes from experience, preferably from working in different environments under a range of different conditions. All hydrologists must learn to discern what is real versus what is just a model estimate.

Learn what is big and what is little. Although the specific details are complex, often there are only a few dominant controls on the movement and storage of water for a given situation. Practicing hydrologists need to learn what is big and what is little, and spend time on the dominant controls relevant to the problem of concern rather than trying to refine a number or an input that ultimately doesn't greatly affect the result.

Land use can have a bigger effect on erosion and sedimentation rates than runoff. I began my career as a forest hydrologist, studying how timber harvest affects the amount and timing of runoff. After studying how forest management activities affect stream channel characteristics, I found that increasing management was associated with an increase in fine sediment rather than channel incision, indicating that erosion and sedimentation were bigger concerns than the changes in runoff. I then began studying erosion rates in forested areas, and quickly realized that roads, fires, and channel erosion due to urbanization can each increase erosion rates by several orders of magnitude. Timber harvest, if done carefully, usually has very little effect on runoff and erosion. Bottom line is that in forested areas erosion and sedimentation is the biggest concern, and one should focus on roads, fires and urbanization—most everything else is just noise!

Soil cover is the key to watershed management. The primary task of the watershed manager is to minimize the increases in runoff and erosion, and this means maintaining or increasing the infiltration rate in order to minimize the amount of surface runoff. Numerous studies in different environments indicate that erosion rates are minimized if there is at least 60-70 percent surface cover (Figure 2). Hence the primary task of the watershed manager is to maintain or establish a good surface cover, as this helps maximize the infiltration rate.

Think globally, act locally. This is a well-known bumper sticker, but it applies to watershed management. If one takes care of local issues by maximizing infiltration, minimizing overland flows, and reducing local pollution sources, this should largely eliminate downstream cumulative effects (MacDonald, 2000).

If you want to help, work in developing countries. The U.S. and other developed countries have rich data sets, tremendous technical expertise, strong legal controls, and have largely solved the basic issues with respect to water supply, pollution, and human well being. In contrast, developing countries typically have very few data, limited technical expertise, and such limited resources that they can only focus on the most basic resource management issues related to human health and survival. So if you want to make a difference, think about working in developing countries.

References

Larsen I.J., L.H. MacDonald, E. Brown, D. Rough, M. J. Welsh, J.H. Pietraszek, Z. Libohova, J.D. Benavides-Solorio, and K. Schaffrath, 2009. Causes of post-fire runoff and erosion: water repellency, cover, or soil sealing? Soil Science Society of America Journal 73: 1393-1407.

MacDonald, L.H., 1993. Developing a field component in hydrologic education. Water Resources Bulletin 29(3):357-368.

MacDonald, L.H., 2000. Evaluating and managing cumulative effects: process and constraints. Environmental Management 26(3): 299-315.

Milly, P.C.D., et al., 2008. Stationarity is dead: whither water management? Science 319: 573-574.

NRC, 1991. Opportunities in the hydrologic sciences. National Research Council, National Academy Press, Washington, D.C. 348 pp.

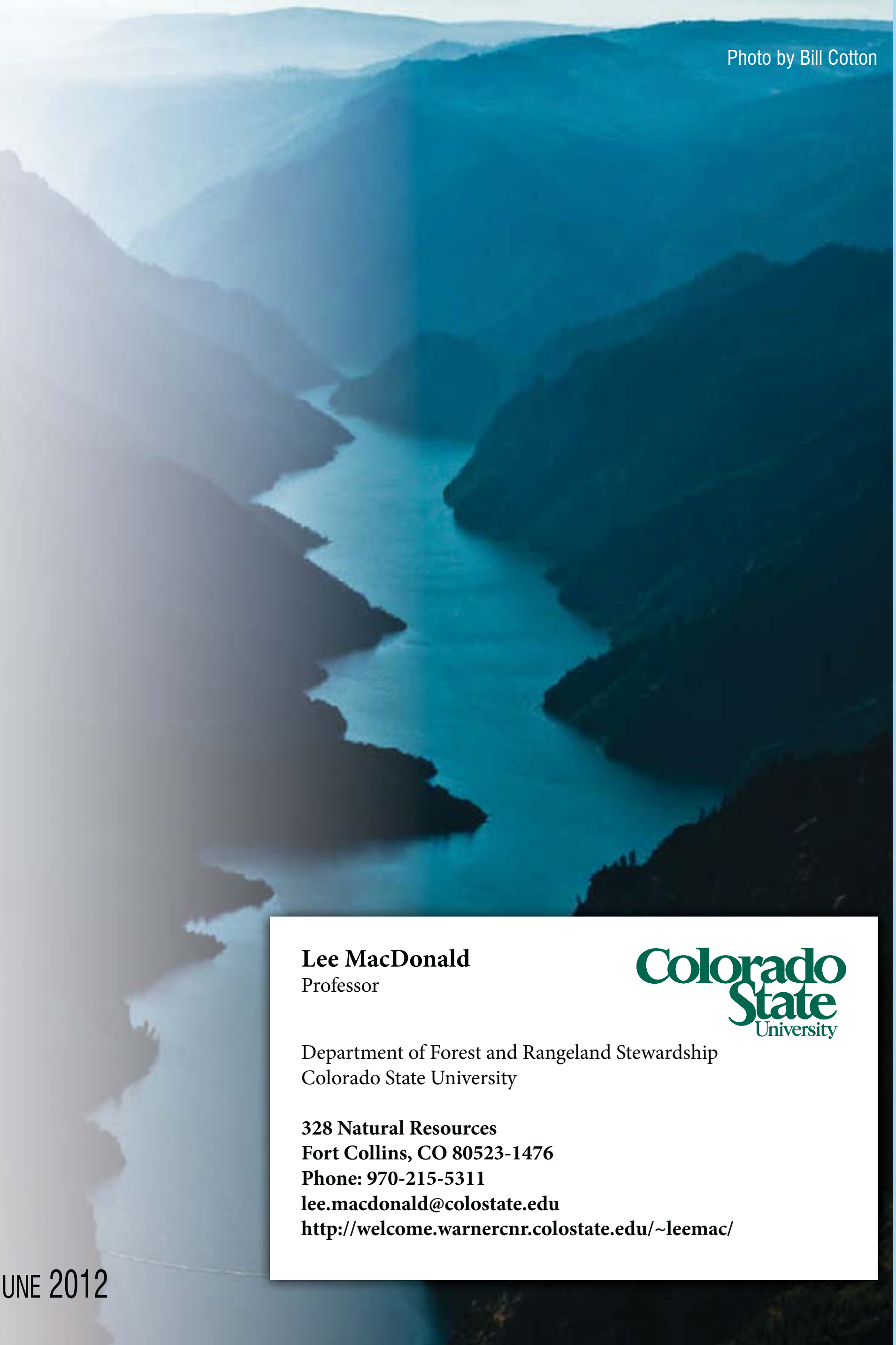


Photo by Bill Cotton

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