Ecohydrology of Water-Controlled Ecosystems
Soil Moisture and Plant Dynamics

Ignacio Rodríguez-Iturbe
Princeton University, New Jersey, USA

Amilcare Porporato
Duke University, North Carolina, USA

CAMBRIDGE UNIVERSITY PRESS
## Contents

*Foreword, Gabriel Katul*  
*Preface*  

1 Introduction  
1.1 Ecohydrology of water-controlled ecosystems  
1.2 Simplifying assumptions  
1.3 Levels of description  
1.4 Temporal scales  
1.5 Spatial dimensions  
1.6 Soil moisture and the cycles of soil nutrients  
1.7 Soil moisture dynamics and ecosystem structure  

2 Stochastic soil moisture dynamics and water balance  
2.1 Soil water balance at a point  
2.2 Probabilistic evolution of the soil moisture process  
2.3 Steady-state probability distribution of soil moisture  
2.4 Water balance  
2.5 Comparison with field data  
2.6 Simpler models of soil moisture dynamics  
2.7 Appendix A. Soil moisture cumulative probability distribution  

3 Crossing properties of soil moisture dynamics  
3.1 Mean first passage times of processes driven by white shot noise  
3.2 Crossing properties of the soil moisture process  
3.3 Duration of excursions between two different levels of soil moisture  
3.4 MFPT’s for minimalistic models of soil moisture  
3.5 Appendix B. Backward differential equation and crossing properties
# Contents

4 Plant water stress  
4.1 Soil-water deficit and plant water stress 86  
4.2 Probabilistic description of static water stress 101  
4.3 Dynamic water stress 107  
4.4 Impact of environmental conditions on dynamic water stress 110  
4.5 Optimal plant conditions 114  
5 Applications to natural ecosystems 117  
5.1 The role of vegetation in the NyIsvley savanna 119  
5.2 Sensitivity to climate fluctuations in a southern Texas savanna 129  
5.3 The role of soil texture in the Colorado shortgrass steppe 140  
5.4 Vegetation patterns along the Kalahari precipitation gradient 149  
5.5 Tree canopy effects in southern African savannas 164  
5.6 Soil moisture balance and water stress in a Mediterranean oak savanna 173  
6 Coupled dynamics of photosynthesis, transpiration and soil water balance: from hourly to growing-season time scale 179  
6.1 Transpiration and soil water balance at the hourly time scale 180  
6.2 Stomatal function 186  
6.3 Leaf carbon assimilation and photosynthesis 189  
6.4 Hourly dynamics 194  
6.5 Comparison with data 198  
6.6 Daily time scale dynamics 200  
6.7 Physical interpretation of the parameters 203  
6.8 Probabilistic dynamics of carbon assimilation 204  
6.9 Mean carbon assimilation and plant water stress 207  
7 Plant strategies and water use 212  
7.1 Extensive and intensive users of soil moisture 213  
7.2 The inverse texture effect in the southern Texas savanna 218  
7.3 Stochastic water availability and adaptation of transpiration characteristics 227  
8 Seasonal and interannual fluctuations in soil moisture dynamics 236  
8.1 Seasonal mean soil moisture dynamics 237  
8.2 Interannual rainfall fluctuations and soil moisture dynamics 250  
8.3 Appendix C 266
Contents

9 Spatial scale issues in soil moisture dynamics 268
   9.1 An assessment of the role of the vertical distribution of soil moisture 269
   9.2 Stochastic soil moisture dynamics along a hillslope 292
10 Hydrologic controls on nutrient cycles 306
   10.1 The carbon and nitrogen cycles in soils 309
   10.2 Modeling the carbon and nitrogen cycle in water-controlled ecosystems 317
   10.3 An application to the Nylsvley savanna 332
   10.4 The problem of nitrogen oxide emissions 350
   10.5 Towards a hierarchy of models 352
11 Hydrologic variability and ecosystem structure 360
   11.1 Tree-grass coexistence and optimization of water stress 362
   11.2 A water-stress-based cellular automaton for tree-grass evolution 372
   11.3 A hierarchical model for tree-grass competition driven by interannual rainfall variability 386
   11.4 Impact of interannual rainfall variability on temporal and spatial vegetation patterns 406

References 417
Species Index 439
Subject Index 440
Colour plates between pp. 178 and 179