

Table of Contents

1. Chapter 1. Introduction.....	1
1.1. Content.....	1
1.2. Context.....	3
1.3. Objectives	4
1.4. Contributions of the doctoral thesis.....	6
2. Chapter 2. A decrease in the regulatory effect of snow-related phenomena in Spanish mountain areas due to climate change.....	7
2.1. Introduction.	7
2.2. Materials and Methods.	11
2.2.1. Variables Analysed	11
2.2.2. ASTER Hydrological Model	11
2.2.3. Selection of the Climate Model	13
2.2.4. Calibration and Validation of the ASTER Model.....	14
2.3. Results.	16
2.3.1. Results of the Validation of the ASTER Model.....	16
2.3.2. Results of the Projections for the Selected Climate Model.....	16
2.3.2.1 <i>Pyrenees</i>	19
2.3.2.2 <i>Sierra Nevada</i>	21
2.3.2.3 <i>Central System</i>	23
2.3.2.4 <i>Cantabrian Mountains</i>	25
3. Chapter 3. Seasonal variability of snow density in the Spanish Pyrenees.....	29
3.1. Introduction.	29
3.2. Materials and Methods.	33
3.2.1. On-Site Manual Sampling and Measurements.....	33
3.2.2. On-Site Non-Destructive Measurements	36

3.2.3. Other Data and Sources of Error.....	38
3.2.4. Analysis Methodology.....	38
3.3. Results.....	40
3.3.1. SDEN Statistics.....	40
3.3.2. Most Representative Automatic TNM Sites.....	42
3.3.3. Identification of Dominant Variables.....	44
3.3.4. Multiple Linear Regressions (MLRs).....	46
4. Chapter 4. Analysis of climate change’s effect on flood risk. Case study of Reinoso in the Ebro river basin	49
4.1. Introduction.....	49
4.2. Materials and Methods.....	53
4.2.1. Overall methodology.....	53
4.2.2. Hazard and risk maps.....	54
4.2.3. Hydrological model. Hijar basin model.....	57
4.2.4. Snow accumulation and Snow melt routine.....	58
4.2.5. Model calibration and validation.....	58
4.2.6. Climate projection.....	59
4.2.7. Calculation of flow rates for different return periods.....	60
4.3. Results.....	62
4.3.1. Flow rate evolution (RCP 8.5).....	62
4.3.2. Hazard and risk maps.....	63
5. Chapter 5. Discussion.....	69
5.1. Overall discussion.....	69
5.2. Limitations of the hydrological model.....	70
5.3. Variations in the pattern of snow-related phenomena in Spanish Mountains due to the climate change effect.....	70
5.3.1. Pyrenees.....	71
5.3.2. Sierra Nevada.....	71
5.3.3. Central System.....	71

5.3.4. Cantabrian Mountains.....	71
5.4. Flood risk increase due to the climate change effect.....	71
5.5. Climate models. Limitations.....	72
5.6. Seasonal and spatial variability of Snow Density in the Spanish Pyrenees.....	72
5.6.1. Comparison between automatic measurements (TNMs) and manual SDEN sampling.....	73
5.6.2. Temporal variability of Snow Density.....	73
5.6.3. Significance of climate drivers.....	73
5.6.4. Multiple Linear Regression models for snow density.....	74
5.6.5. Improvement of automatic measurements (TNMs) network.....	74
6. Chapter 6. Conclusions and future research lines	75
6.1. Conclusions.....	75
6.2. Future research lines.....	78
7. Chapter 7. Final conclusion	79
References	81
Appendix 1 – A Decrease in the Regulatory Effect of Snow-Related Phenomena in Spanish Mountain Areas Due to Climate Change	89
Appendix 2 – Seasonal Variability of Snow Density in the Spanish Pyrenees.....	91
Appendix 3 – Analysis of Climate Change’s Effect on Flood Risk. Case Study of Reinoso in the Ebro River Basin.....	93

