The main goal of this dissertation research is to derive a type of conceptual models for annual water balance at the watershed scale. The proportionality relationship from the Soil Conservation Service Curve Number method was generalized to annual scale for deriving annual water balance model. As a result, a one-parameter Budyko equation was derived based on one-stage partitioning; and a four-parameter Budyko equation was derived based on two-stage partitioning. The derived equations balance model parsimony and representation of dominant hydrologic processes, and provide a new framework to disentangle the roles of climate variability, vegetation, soil and topography on long-term water balance. Three applications of the derived equations were demonstrated. Firstly, the four-parameter Budyko equation was applied to 165 watersheds in the United States to disentangle the roles of climate variability, vegetation, soil and topography on long-term water balance. Secondly, the one-parameter Budyko equation was applied to a large-scale irrigation region. The historical annual total water storage change were reconstructed for assessing groundwater depletion due to irrigation pumping by integrating the derived equation and the satellite-based GRACE (Gravity Recovery and Climate Experiment) data. Thirdly, the one-parameter Budyko equation was used to model the impact of willow treatment on annual evapotranspiration through a two-year field experiment in the Upper St. Johns River marshes. An empirical relationship between the parameter and willow fractional coverage was developed, providing a useful tool for predicting long-term response of evapotranspiration to willow treatment.