In this work, we start with a review of the development of Boussinesq theory for water waves covering the period from 1872 to date. Previous reviews have been given by Dingemans, Kirby, and Madsen & Schäffer. Next, we present our most recent high-order Boussinesq-type formulation valid for fully nonlinear and highly dispersive waves traveling over a rapidly varying bathymetry. Finally, we cover applications of this Boussinesq model, and we study a number of nonlinear wave phenomena in deep and shallow water. These include (1) Kinematics in highly nonlinear progressive deep-water waves; (2) Kinematics in progressive solitary waves; (3) Reflection of solitary waves from a vertical wall; (4) Reflection and diffraction around a vertical plate; (5) Quartet and quintet interactions and class I and II instabilities; (6) Extreme events from focused directionally spread wave fields; (7) Bragg scattering from an undular sea bed; (8) Run-up of non-breaking solitary waves on a beach; and (9) Tsunami generation from submerged landslides.