Multiplying by 2 and using (6), (7), and (10) gives

$$\boxed{\frac{\partial}{\partial t}\left(\frac{H_\theta q^2}{mn}\right) + \frac{\partial}{\partial \xi}\left(\frac{H_\theta u q^2}{n}\right) + \frac{\partial}{\partial \eta}\left(\frac{H_\theta v q^2}{m}\right) + \frac{\partial}{\partial s}\left(\frac{H_\theta \Omega q^2}{mn}\right) - \frac{\partial}{\partial s}\left[\frac{K_q}{mnH_\theta}\frac{\partial}{\partial s}(q^2)\right] = 2\frac{H_\theta K_M}{mn}\left[\left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2\right] + \frac{2H_\theta K_H}{mn}N^2 - \frac{2H_\theta q^3}{mnB_1 l} + \frac{H_\theta}{mn}Q_q} \tag{13}$$

Surface Boundary Conditions

$$\frac{H_\theta \Omega}{mn} = 0 \qquad @\ s=0 \quad (z=\zeta(\xi,\eta,t)) \tag{14}$$

$$\frac{K_q}{mnH_\theta}\frac{\partial q^2}{\partial s} = \frac{B_1^{2/3}}{\rho_0}\left[(\tau_s^\xi)^2 + (\tau_s^\eta)^2\right] \tag{15}$$

$$H_\theta K_M\left[\frac{\partial u}{\partial z}, \frac{\partial v}{\partial z}\right] = \frac{1}{\rho_0}\left(\tau_s^\xi, \tau_s^\eta\right) \tag{16}$$

$$H_\theta K_H\left[N^2\right] = \frac{Q}{\rho_0 c_p} \tag{17}$$

Bottom Boundary Conditions

$$\frac{H_\theta \Omega}{mn} = 0 \qquad @\ s=1 \quad (z=h(\xi,\eta)) \tag{18}$$

$$\frac{K_q}{mnH_\theta}\frac{\partial q^2}{\partial s} = \frac{B_1^{2/3}}{\rho_0}\left[(\tau_b^\xi)^2 + (\tau_b^\eta)^2\right] \tag{19}$$

$$H_\theta K_M\left[\frac{\partial u}{\partial z}, \frac{\partial v}{\partial z}\right] = \frac{1}{\rho_0}\left(\tau_b^\xi, \tau_b^\eta\right) \tag{20}$$

$$H_\theta K_H\left[N^2\right] = 0 \tag{21}$$