We present a theoretical model and its efficient numerical implementation for the simulation of wavelength-swept waveform propagation in fiber systems such as Fourier domain mode-locked (FDML) lasers, fully accounting for the polarization dynamics in fiber spools and further polarization-dependent optical components in the setup. This approach enables us to perform long-time simulations of the FDML laser dynamics over more than 100,000 cavity round trips, as required for some FDML configurations to ensure convergence to the steady-state operating regime. The model is validated against experimental results for single propagation through a fiber spool and for stationary FDML operation. The polarization dynamics due to the fiber spool, inducing polarization-mode dispersion, bending birefringence as well as cross-phase modulation, and other optical components such as the Faraday-rotating mirror used for polarization compensation is thoroughly investigated.