The predictive ability of a hybrid model integrating the Firefly Algorithm (FFA), as a heuristic optimization tool with the Multilayer Perceptron (MLP-FFA) algorithm for the prediction of water level in Lake Egirdir, Turkey, is investigated. The accuracy of the hybrid MLP-FFA model is then evaluated against the standalone MLP-based model developed with the Levenberg–Marquadt optimization scheme applied for in the backpropagation-based learning process. To develop and investigate the veracity of the proposed hybrid MLP-FFA model, monthly time scale water level data for 56 years (1961–2016) are applied to train and test the hybrid model. The input combinations of the standalone and the hybrid predictive models are determined in accordance with the Average Mutual Information computed from the historical water level (training) data; generating four statistically significant lagged combinations of historical data to be adopted for the 1-month forecasting of lake water level. The proposed hybrid MLP-FFA model is evaluated with statistical score metrics: Nash–Sutcliffe efficiency, root mean square and mean absolute error, Wilmott’s Index and Taylor diagram developed in the testing phase. The analysis of the results showed that the hybrid MLP–FFA4 model (where 4 months of lagged combinations of lake water level data are utilized) performed more accurately than the standalone MLP4 model. For the fully optimized hybrid (MLP-FFA4) model evaluated in the testing phase, the Willmott’s Index was approximately 0.999 relative to 0.988 (MLP 4) and the root mean square error was approximately 0.029 m and compared to 0.102 m. Moreover, the inter-comparison of the forecasted and the observed data with various other performance metrics (including the Taylor diagram) verified the robustness of the proposed hybrid MLP-FFA4 model over the standalone MLP4 model applied in the problem of forecasting lake water level prediction in the current semi-arid region in Turkey.