Long-Term Mean Annual Water Temperature for Stream Reaches in the United States Pacific Northwest

Purpose

This data set was compiled as part of an assessment of water vulnerability in the Columbia River basin (Chang, *et al*., 2013 this paper).

Methods

Long-term mean annual water temperature (degrees Celsius) was estimated for each reach in the E2RF1 stream network (Brakebill and Terziotti, 2011) located within the Pacific Northwest region of the United States (HUC2 = 17; the Columbia River basin, the Puget Sound watershed, the coastal drainages of Washington and Oregon, and the closed basins in southern Oregon). Multiple linear regressions were used to select reach-scale watershed attributes (explanatory variables) for predicting the long-term mean annual water temperature (dependent variable) at a set of USGS water-quality monitoring stations. The water temperature data used in the regressions were obtained from the USGS National Water Information System (USGS, 2011). The final data set of water-temperature measurements was obtained from 125 water-quality monitoring stations located on streams where the water-temperature record satisfied the following criteria: 1) spanned at least 10 years ; 2) included at least 50 measurements representing individual days; and 3) at least 20 percent of the samples were collected during each season. Water-quality monitoring stations that were influenced by geothermal activity were not included. The reach-scale watershed attributes used in the multiple linear regressions were compiled as part of regional assessment of surface waters across the Pacific Northwest using the

USGS SPARROW model (Wise and Johnson, 2011; Schwarz *et al.*, 2006; Wieczorek and Lamotte, 2011).

Each water-quality monitoring station was identified with a reach-scale watershed and its associated attributes. Multiple linear regressions were completed for three separate data sets based on the primary land cover within the reach-scale watersheds obtained from the 2001 National Land Cover Database (NLCD)(Homer, *et al*., 2004): forest land (n = 66), agricultural land (n = 25), and scrub land (n = 34). This distribution of land cover generally reflected the distribution of land cover for the entire set of E2RF1 reach-scale watersheds. There were a small number of watersheds (< 1% of the total number in the E2RF1 reach-scale watersheds) where the primary land cover type was developed land. No regression equations were developed for these reaches because of the small number of water-quality stations (6) meeting the selection criteria. All significant explanatory variables (p-value < 0.05) were considered for inclusion in the regression equation for each land cover category. Additional analysis revealed, however, that some of these significant explanatory variables were strongly correlated with other variables (rho > 0.50 or < -0.50; p-value < 0.0001) and were not included in the final regression equations. The results from the multiple linear regressions were used to predict the long-term mean water temperature for each reach in the E2RF1 network. The following prediction equations were used:

Regression Equations:

Primary Land Cover Type	Prediction Equation
Forest land (NLCD 41,42,43)	mean_wtemp_C = 1.32461+0.53185*TMAX30_MEAN + 0.00003261*demtarea + 0.00028297*PPT30MEAN - 0.16748 *rchslope; R^2 = 0.620; RMSE =1.37;
Agricultural land (NLCD 81,82)	mean_wtemp_C = -1.38503+0.79183**TMAX30_MEAN - 0.00229*STRM_DENS ; R^2 = 0.807; RMSE =0.91.;
Scrub land (NLCD 52)	mean_wtemp_C = 2.69545 + 0.48557*TMAX30_MEAN- 0.00641*MEAN_RCHRG; R^2 = 0.541; RMSE =1.30;

where :

mean_wtemp_C is an estimate of the long-term mean water temperature in degrees C

and the reach-scale watershed attributes are defined as follows (with an interpretation of the results for each attribute).

TMAX30_MEAN = mean annual maximum daily air temperature for the period 1971–2000 (degrees C). The positive coefficient for this explanatory variable reflects the positive relationship expected between maximum mean annual air temperature and long-term mean annual water temperature. This variable explained most of the variation in each of the regression equations and, therefore, was the most powerful predictor of long-term mean annual water temperature.

Demtarea = total upstream drainage area (km2). The positive coefficient for this explanatory variable might be due to the tendency of watersheds to include a larger percentage of developed land (agricultural and urban areas) than smaller watersheds, and runoff from agricultural and urban areas is often reused water that is warmer than source water.

PPT30MEAN = mean annual precipitation for the period 1971 – 2000 (mm). The positive coefficient for this explanatory variable might be due to the tendency of watersheds with higher precipitation to have a higher percentage of total runoff from surface water compared to watersheds with lower precipitation. Watersheds with a high proportion of surface runoff likely have higher mean annual water temperatures than watersheds with a lower percentage, because surface water is more sensitive to air temperature than ground water (and air temperature is greater than ground water temperature during most of the year throughout most of the Pacific Northwest).

Rchslope = reach slope (percent); STRM_DENS = stream density (m/m^2); and MEAN_RCHRG = mean estimate of ground recharge (mm/yr). The negative coefficients for these explanatory variables might be due to the tendency of watersheds with higher reach slopes, stream density, and ground water recharge to have a higher contribution of total flow from ground water compared to watersheds with lower stream density. This is because ground water is typically cooler than surface water.

RMSE is the root mean squared error of the regression (that is, the standard deviation of the unexplained variance in degrees C). Figure 1 compares the predicted and measured long-term mean annual water temperature values for the 125 water-quality stations that were used in the regression equations.

There 1730 E2RF1 reaches for which no predictions were made of mean annual water temperature. For 1509 of these reaches the reason was that at least one of the reach-scale watershed attributes was outside the range of values used in the regression analysis. For 220 of these reaches the reason was that the primary land cover in the corresponding reach-scale watershed was not forest land, agricultural land, or scrub land. There was also one line segment is in the E2RF1 stream network (RF1-ID = 527404) that did not actually represent a stream. Its inclusion reflects the requirement that each catchment in the E2RF1 data base have an associated reach. No prediction of long-term mean water temperature was made for this line segment. The final data set contained mean annual water temperature predictions for 10,309 of the 12,039 E2RF1 stream reaches.

The meta data for this geospatial data set will contain a caveat that warns the user about large differences in predicted water temperature between contiguous reaches that have different primary land cover types and non-contiguous reaches in the same area that have different primary land cover types.

Literature Cited

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