**A Novel Approach in Determining Changes in Consumptive Use**

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**Abstract.** With the growing pressure on ensuring that water resources are identified for each river basin, one salient component is determining the change in consumptive use over a given period of time. Consumptive water use may be defined as that portion of the withdrawal from a river basin which is not returned. The cause of consumptive use varies considerably, but can be the result of septic tank usage, improper irrigation practices and evaporation from large industrial plants which require substantial evaporation for cooling. The determination of consumptive use has historically been approached by balancing water treatment and wastewater discharges and determining the differential. However, this approach frequently doesn’t address the temporal and spatial complexity of dramatically-changing precipitation and groundwater flows on water basin flow rates over long periods of time. In this paper, the authors propose a solution to this problem which will enable flow rates to be normalized for changing weather conditions over time.

While it is understood that river flow is hydrologically dependent on precipitation, among other variables, sensitivity analyses quantify the relationships between a dependent variable (e.g., flow) and causal variables (e.g., precipitation and consumptive use). The sensitivity of relationships among variables can be computed through modeling, which varies from simple statistical relationships to complex physically-based mechanistic methods. On the other hand, artificial neural networks (ANNs) are a form of “machine learning” from the field of Artificial Intelligence (AI) that employ a flexible mathematical structure that is loosely based on the biological nervous system (Hinton, 1992). In an ANN, the functional relationships are defined by the data points themselves.

**River Gaging Data – Compilation and Processing**

To study water loss/gain within each segment, a flow difference, or delta, consisting of the segment outflow minus the segment inflow, is to be calculated. An optimal time delay for each input should be determined by lagging the inflow gage by incremental time periods (for example, “days”) and looking for the peak correlation to the segment outflow. The difference in flow for each river basin segment can then be calculated as follows:

\[
\text{SnQdiff} = \text{Qout} - (\text{Qin}_1(\tau_1) + \text{Qin}_2(\tau_2))
\]

In which:

- \(\text{SnQdiff}\) = Qdiff for each segment number, 1 to n, (cfs)
- \(\text{Qin}\) = Flow into each segment (cfs)
- \(\text{Qout}\) = Flow out of each segment (cfs)
- \(\tau\) = time delay between inflow and outflow (days)

The flow (Q) data is next processed for the purpose of looking at change in consumptive use over the period of record. A reasonable moving window average (MWA) of SnQdiff is next calculated to smooth the signal to reduce high-frequency variability while preserving lower frequency variability. This MWA (SnQdiff) is the output (predicted variable) for each of the weather models.

**Weather Data – Compilation and Processing**

Time series clustering can be used to group weather stations by like behavior (Weiss and Indurkhya, 1992). Gaps in precipitation data can be filled using data available from other stations within the same cluster. station-to-station correlations for the maximum...
temperature (TMAX) will tend to be high and so TMAX data can be filled using ANNs to correlate each station’s TMAX to the station with the most complete data set for TMAX.

There are many contributors to consumptive use (e.g., cooling towers, septic tanks, pipe leaks, faulty irrigation practice) about which little or no data are available. However, by using ANNs to account for the effects of weather on flow variability, the change in water loss in the system attributable to anthropogenic impacts over the period of record can be derived. The novel approach developed for accurately estimating consumptive use is as follows:

**Step 1.** A river basin should be divided into segments defined by stream gauging stations. For each segment a flow difference ($Q_{\text{diff}}$) is next calculated, consisting of the difference between flow entering the segment ($Q_{\text{in}}$) and flow leaving the segment ($Q_{\text{out}}$). The calculated variable, $Q_{\text{diff}}$, is dependent on both weather and anthropogenic impacts (withdrawals and discharges).

**Step 2.** The second step in the analysis involves extracting the variability of $Q_{\text{diff}}$ that can be ascribed to weather by using ANNs to model $Q_{\text{diff}}$ using only weather data as inputs. This provides an accounting of the variability in $Q_{\text{diff}}$ that is attributable to variability in the weather inputs solely.

**Step 3.** The third step is to estimate the change in consumptive use over the period of record. Model residual flow ($Q_{\text{res}}$) is the difference between the measured output data and the model prediction. In addition, the model residual flow would also include the variability due to unknown causes such as measurement error, noise, and “unknown disturbances” or consumptive use. The change in consumptive use over the period of record can be calculated using a linear regression of $Q_{\text{res}}$ over the period of data record and calculating a value for $Q_{\text{res}}$ at the start of the data record ($Q_{\text{res}_{\text{start}}}$) and a value for $Q_{\text{res}}$ at the end of the data record ($Q_{\text{res}_{\text{end}}}$). The change in residual flow, $Q_{\text{res}_{\text{end}}} - Q_{\text{res}_{\text{start}}}$ is equal to the change in consumptive use ($\Delta Q_{\text{consumptive}}$) over the period of record.

Finally, this novel approach can be used when detailed data regarding water use and disposal is unavailable—a common problem with large and complex river basins.

**LITERATURE CITED**

