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**Criterion 4. Indicator 24. Percent of surface water in forest areas with significant variation from historic range for dissolved oxygen, temperature, electrical conductivity, acidity (pH), and sedimentation.**

**A. Introduction**

This indicator measures aspects of aquatic health and water quality, including dissolved oxygen, temperature, levels of chemicals and pollutants (electrical conductivity), pH, and sedimentation in forests. Other more specific variables could also be used to assess water quality, but the five selected represent a broad range of chemical and physical properties. Changes in these variables over time can show trends that may indicate whether current or past management practices are positively or adversely affecting water quality. Land management practices can then be adjusted to maintain or improve water quality for drinking, fisheries, industry, recreation, agriculture, and other uses. Declines in water quality could indicate that forest-related activities are having adverse effects on aquatic ecosystem health.

Although the guidelines for the Montreal criteria and indicator process request comparison of a variable's variation to historic ranges, this was not attempted because readily accessible historic data were unavailable. Instead, comparison was made within current data by analyzing standard deviations of available data. Therefore, this study is basically an exploratory effort to link five water quality variables to available forest cover information (from Forest Inventory and Analysis or FIA) at a national scale.

**B. Definitions/background:**

**Dissolved oxygen** – Dissolved oxygen is the amount of oxygen gas dissolved in a given quantity of water at a given temperature and atmospheric pressure. It is usually expressed as a concentration in parts per million or as a percentage of saturation. Dissolved oxygen concentrations are most often reported in units of milligrams of gas per liter of water (mg/l), which is equivalent to parts per million (ppm).

(<http://wow.nrri.umn.edu/wow/under/parameters/oxygen.html>)

**Electrical conductivity** – Electrical conductivity (EC) estimates the amount of total dissolved salts, or the total amount of dissolved ions in the water. EC is controlled by geology (rock types), the size of the watershed relative to the area being measured (e.g., a lake), other sources of ions, pollutants (both point source and nonpoint source), urban and agricultural runoff, water evaporation, bacterial metabolism, and atmospheric inputs of

ions. Electrical current flow increases with increasing temperature, so the EC values are automatically corrected to a standard value of 25°C and the values are technically referred to as *specific electrical conductivity*. Electrical conductivity is measured in microSiemens per centimeter ( $\mu S/cm$ ), which is a measure of electrical current flowing through the water in proportion to the concentration of dissolved ions—the more ions, the more conductive the water resulting in a higher EC value.  
(<http://wow.nrri.umn.edu/wow/under/parameters/conductivity.html>).

**Hydrologic Unit Code (HUC)** – A hierarchical coding system developed by the U. S. Geological Survey (USGS) to identify geographic boundaries of drainage areas of various sizes. The United States is divided and subdivided into successively smaller hydrologic units (HUCs), which are nested within each other. The smallest units are called HUC-8 watersheds, which are nested within HUC-6 basins, which are nested within HUC-4 subregions, which are within HUC-2 regions. The largest and most inclusive unit, the HUC-2 or region, is a major geographic area that contains either the drainage area of a major river (such as the Missouri region) or the combined drainage areas of a series of rivers (such as the Texas-Gulf region). There are twenty one regions, two hundred twenty two sub-regions, three hundred fifty two basins, and two thousand one hundred fifty watersheds in the United States. HUCs provide a uniform, nationwide area framework for studying the Nation’s hydrology  
(<http://water.usgs.gov/GIS/huc.html>).

**pH** – The pH of a water sample measures the concentration of hydrogen ions as a negative logarithm of the hydrogen ion ( $H^+$ ) concentrations, so at higher pH, there are fewer free hydrogen ions. A change of one pH unit reflects a ten-fold change in the concentrations of the hydrogen ion, because of log scaling. The pH scale ranges from 0 to 14. A pH of 7 is considered to be neutral, less than 7 is acidic; and greater than 7 is basic. The pH of water determines the solubility and biological availability of chemical constituents such as nutrients and heavy metals. Pollution can lead to increases or decreases in pH, which can have profound impacts on aquatic life.  
(<http://wow.nrri.umn.edu/wow/under/parameters/ph.html>)

**Sediment** – Sediment is comprised of finely divided solid particles that have been transported by wind, water, or ice and subsequently deposited in water. This study considers sediment as weight of suspended material larger than 0.062 mm (sieve size) divided by total sample weight expressed in percent. Problems associated with sediment include pollutants (nutrients, metals, pesticides, organics, etc.) that are bound to and transported by sediment, changes to chemical and biological river systems from excess sediment transport, and increased hazards such as debris flows, landslides, and channel alterations during floods. Channel modifications from urbanization, agricultural practices, and flood control have been identified as the primary causes of human-caused sediment problems in the United States. Forest fires also play a role in altering the hydrologic regime of an area, with increased flooding and sediment transport as a result. Sedimentation can negatively affect fish spawning sites, backwater areas, and stream bank stability for riparian vegetation. [reference: Koltun, Landers, Nolan, Parker,

Sediment transport and geomorphology issues in the water resources division, proceedings of USGS sediment workshop Feb. 4–7, 1997]

**Temperature** – Water temperature is a water quality parameter considered under the Clean Water Act. It is an important aspect of aquatic habitat necessary to support beneficial water uses. Water temperature influences metabolism, behavior, and mortality of aquatic species. For example, salmonids (salmon and trout) are cold-water fish that are particularly sensitive to increases in temperature. Temperature is measured in degrees Celsius. (<http://wow.nrri.umn.edu/wow/under/parameters/temperature.html>)

**TMDL** – Total maximum daily load (TMDL) is a water quality standard (derived from section 303(d) of the Federal Clean Water Act) that is often used as a tool to assess water quality of a pollutant at a local level. A TMDL establishes the maximum amount of an impairing substance or stressor that a water body can assimilate and still meet acceptable conditions. However, there are no accepted TMDLs at a national scale, and, therefore, TMDLs were not considered for this study.

### **C. Data/Analysis Methods**

Although considerable water data has been collected by USGS, Environmental Protection Agency (EPA), Forest Service, and other agencies, it is not easy to access this data in a consistent format. In fact, researching, acquiring, and reformatting data consumed most of the effort in this study.

After talking to many agencies and testing their data downloading capabilities, the USGS National Water-Quality Assessment (NAWQA) data warehouse was the only reasonable source of information for the short timeframe of this study ([http://water.usgs.gov/nawqa/nawqa\\_home.html](http://water.usgs.gov/nawqa/nawqa_home.html)). There is much more USGS (NWISWeb <http://waterdata.usgs.gov/nwis>) and EPA (STORET <http://www.epa.gov/storet/index.html>) water quality data, but acquiring CDs from database managers and spending months on data input and quality editing was beyond the scope of this study. The Forest Service's Natural Resources Information System (NRIS) water module is also compiling USGS and EPA water data, but it is years away from completion and it will probably be of little value for strategic national scale analyses because of its national forest-scale design.

The NAWQA program was started in 1991 and now includes fifty major river basins in the United States. Major additions were included in 1994, 1997, and 1999 and the program will likely continue to expand. Depending upon which NAWQA variable selected, data for the entire U.S. were downloaded in two to three groups. National scale downloading seemed outside the scope of the NAWQA design but the USGS database managers were helpful in for working around problems.

The scope of the analysis was limited to the forty eight continental States, which reduced the number of HUC-8 watersheds to two thousand one hundred two. For each of the five variables there were 15,000 to 33,000 measurements from 370 to 550 HUC-8 watersheds

(table 24.1). Each HUC-8 included about four measurement stations and each station included about 2 years of measurement on average. Some stations included 10 years of data, but the 2 year average indicates the program is still in a startup phase.

The median value of a variable within a HUC-8 (for all available data for all years) was the summary statistic selected for analyses. All variables were examined for temporal variation from month to month, but only dissolved oxygen and water temperature showed strong seasonal trends. For these two variables, the median winter (Nov., Dec. Jan.) and median summer (June, July, Aug.) values were used for analysis. Monthly summary of electrical conductivity showed a slight spike in July but it was not separated out.

Because the analysis included the entire United States, a method was needed to interpolate a median value for those HUC-8s not yet included in the NAWQA program. Interpolation was done, computing medians for all “higher order” HUCs, and then scaling up (for each missing HUC-8) until a median was available. For example, the HUC-6 median was used if available but if the HUC-6 was also missing, the HUC-4 was used, and so forth. Because some data were available for all HUC-2s, this method resulted in data for every HUC-8. The “scaling up” reduced the sensitivity of the data for watershed analysis, because about three-fourths of the watersheds used a higher order value and about one-half required the highest order HUC-2 (table 24.2).

The FIA database was used to subset the NAWQA data to forested watersheds. Because the FIA data was not classified by HUC-8, the HUC-8 analysis was cross-walked to a county scale to incorporate the forest data. First, a weight was calculated for the proportion of forest area in each HUC-8:

$$wt = C_F \left( \frac{C_{HUC}}{C_A} \right)$$

where

$$C_F = \text{county forest area from FIA data} \tag{1}$$

$$C_{HUC} = \text{area of HUC 8 within county}$$

$$C_A = \text{total county area}$$

A weighted mean (using eq. 1) was then calculated from all HUC-8 median values within each county. The weighting worked best where the county was either not forested or heavily forested. Many sparsely forested western counties (often with only riparian corridors) were included because no minimum county forest area used.

Thresholds for comparison were calculated for one and two standard deviations from mean (of county data) for regions in the United States, following the USDA Forest Service RPA assessment regions. The Rocky Mountain and Pacific Coast regions were combined, because of low data numbers. By combining the two regions, the sample size in the West was comparable to the North and South. Depending upon the variable, the upper or lower standard deviations were compared to the rest of the data. For example, low dissolved oxygen values were critical for this variable, so lower standard deviations were studied. But for temperature, the upper standard deviations were more important.

## **D. Results/Discussion**

### **Dissolved Oxygen**

Lower thresholds are most important for dissolved oxygen because oxygen limits many biological processes. Because of a seasonal trend, the analysis was split into winter and summer. Thresholds for two standard deviations below the mean included less than 6 percent of the counties for all regions and seasons (figure 24.1). From 85 to 91 percent of the counties were above the one standard deviation threshold. The lower standard deviations were mostly in the Southwest and Southeast except for some curious lows in the upper Lake States (figure 24.2).

### **Temperature**

The upper threshold for temperature is most important because of the threat of global warming and deforestation of stream channels. Less than 5 percent of the counties were more than two standard deviations for regional means, while 13 to 23 percent were more than one standard deviation from regional means (figure 24.3). Except for the summer in upper Midwest, the upper standard deviations were generally in the southernmost parts of respective regions, which suggests RPA regions might be too large for a temperature analysis. Regions based on air temperature or other ecological variables might be more useful.

### **Specific Electrical Conductivity**

Like temperature, the upper thresholds are most important for EC, because it increases in proportion to the concentration of dissolved ions. From 8 to 20 percent of the counties were over one standard deviation from the regional county means. Less than 4 percent were two standard deviations away (figure 24.5). The highest ECs are in the Southwest, Kentucky, and Mississippi River counties (figure 24.6). The shape of the cumulative frequency is different from the North and West, which warrants further study. Also, the large range of EC (not shown on fig 24.5) at roughly 1000, 2000, and 3000  $\mu S/cm$  for respective North, South, and West regions probably confounded interpretation of standard deviation. In future work, a transformation ought to be considered.

### **pH**

The lower thresholds of pH are important indicators of acidic conditions from pollutants. The cumulative frequency of the West is different and less acidic than in the South and North (figure 24.7). Percentiles below one and two standard deviations are similar for all regions but they correspond to different pH ranges. The South has the most acidic conditions with almost half the counties below pH 7.0. The areas of highest pH are the Northeast, Southeast coastal States, and Pacific Northwest (figure 24.8). The low values in the Pacific Northwest are above 7.0 but mostly below 7.0 in North and South.

## **Sediment**

The upper thresholds of sediment are important for assessing excessive amounts of material in water. Because the data distribution was clustered toward higher sediment percentages (with medians around 80 percent sediment), two standard deviations were outside the range of the data. From 7 to 13 percent of the data exceeded one standard deviation from regional county means (figure 24.9). Areas of greatest sediment were the lower Mississippi River counties, the Southeast, the upper Lake States, lower Colorado River counties, and some interior West counties in agriculture regions.

## **D. Conclusion**

Strict interpretation of these data is difficult because the thresholds have not been equated to critical values nor are standard deviations appropriate for all data distributions.

However, this analysis represents a consistent first approximation of assessing water quality in forest areas in the United States. Future work ought to consider three things:

1. FIA data should be classified and analyzed with HUC-8 units. This would eliminate the need for a county crosswalk and would allow much more creative analyses of actual water data.
2. Thresholds of important must be devised or methods present here must be refined to accommodate the non-normal distributions.
3. More water quality data exists besides that collected by NAWQA. These should be included and examined for past trends. This might be done in connection with legacy FIA data; particularly in the South where many extreme values were observed for all variables.

Table 24.1. Summary of NAWQA water quality data, 1991–2000.

| <b>Water quality variable</b> | <b>No. of measure-ments</b> | <b>No. of HUC-8 water-sheds</b> | <b>No. measure-ments per yr per station per HUC-8</b> | <b>Mean No. of yrs per HUC-8</b> | <b>Mean No. of stations per HUC-8</b> |
|-------------------------------|-----------------------------|---------------------------------|---|----------------------------------|---------------------------------------|
| Dissolved oxygen              | 29,717                      | 544                             | 4.7   | 2.2                              | 4.3                                   |
| Temperature                   | 32,951                      | 549                             | 4.9   | 2.3                              | 4.5                                   |
| Electrical conductivity       | 33,024                      | 545                             | 4.9   | 2.3                              | 4.5                                   |
| pH                            | 31,036                      | 548                             | 4.7   | 2.2                              | 4.5                                   |
| Sediment                      | 15,017                      | 371                             | 5.6   | 2.2                              | 3.1                                   |

Table 24.2. Of the 2,102 HUC-8 watersheds, data was available for 17 to 26 percent. Missing data was estimated from higher order watersheds. For example, if HUC-8 was missing then HUC-6 was used; if HUC-6 was also missing then HUC-4 was used and so forth.

| <b>Water quality variable</b> | <b>HUC-8</b>               | <b>Higher order HUC data used</b> |          |          |
|-------------------------------|----------------------------|-----------------------------------|----------|----------|
|                               | <b>available</b>           | <b>6</b>                          | <b>4</b> | <b>2</b> |
|                               | ----- <i>numbers</i> ----- |                                   |          |          |
| Dissolved oxygen              |                            |                                   |          |          |
| winter                        | 356                        | 505                               | 123      | 1118     |
| summer                        | 513                        | 408                               | 111      | 1070     |
| Temperature                   |                            |                                   |          |          |
| winter                        | 372                        | 489                               | 123      | 1118     |
| summer                        | 520                        | 401                               | 111      | 1070     |
| Electrical conductivity       | 544                        | 393                               | 121      | 1044     |
| pH                            | 546                        | 391                               | 121      | 1044     |
| Sediment                      | 371                        | 403                               | 94       | 1234     |

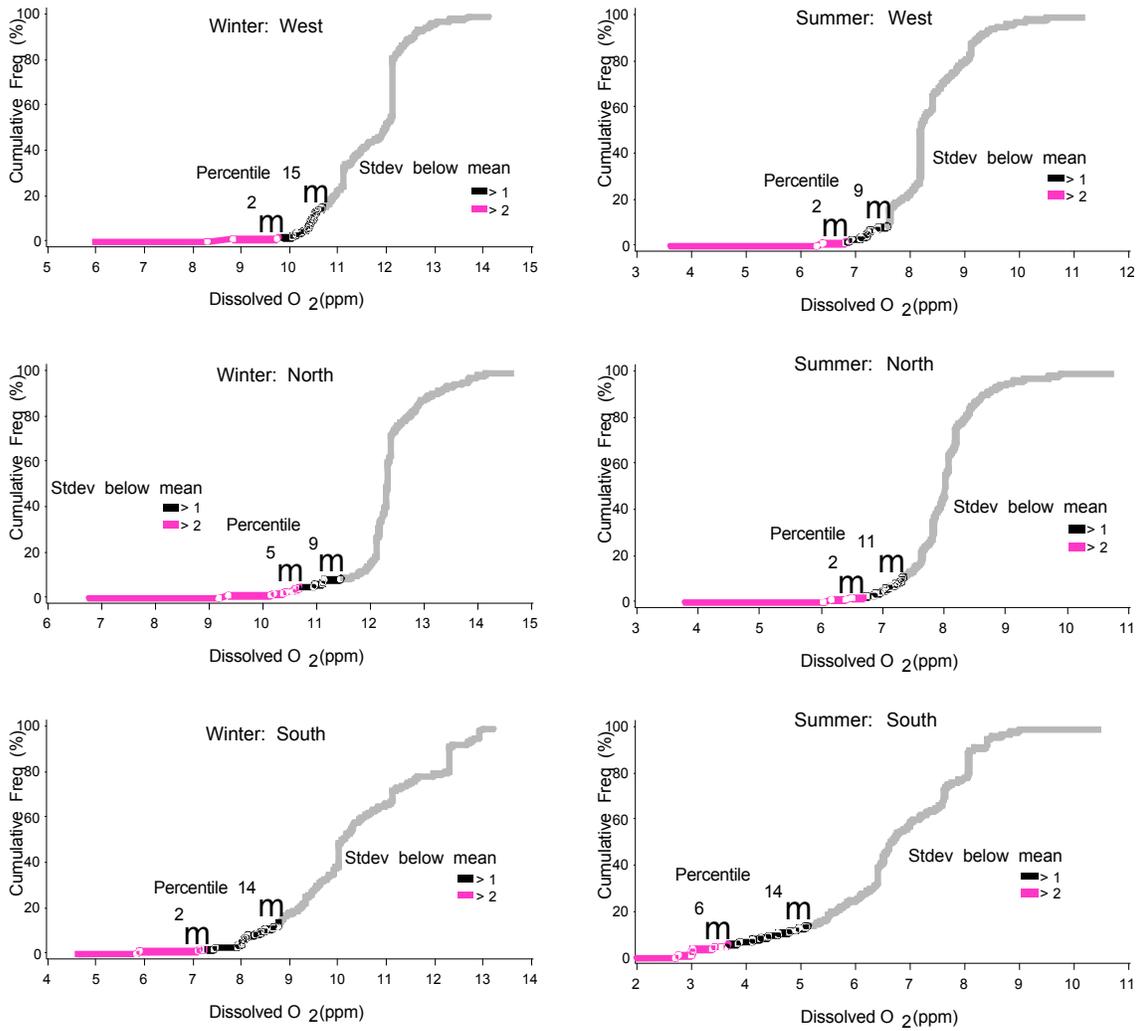


Figure 24.1. Cumulative frequency of dissolved oxygen in streams and rivers of forested counties in the United States, 1991 to 2000. Percentiles for counties one and two standard deviations below the mean are identified to assess lower thresholds for respective regions and seasons.

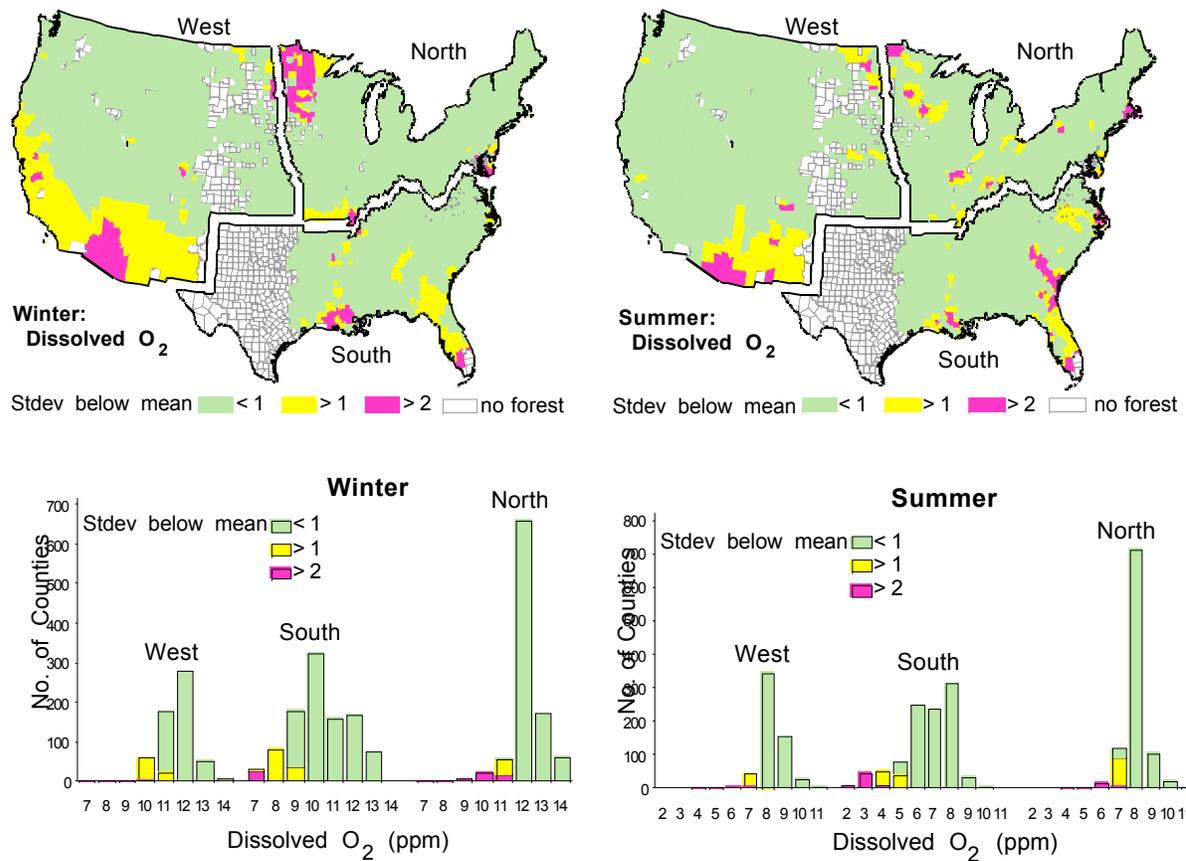


Figure 24.2. Distribution and location of counties one and two standard deviations below mean dissolved oxygen in streams and rivers of forested counties for respective regions and seasons, 1991 to 2000.

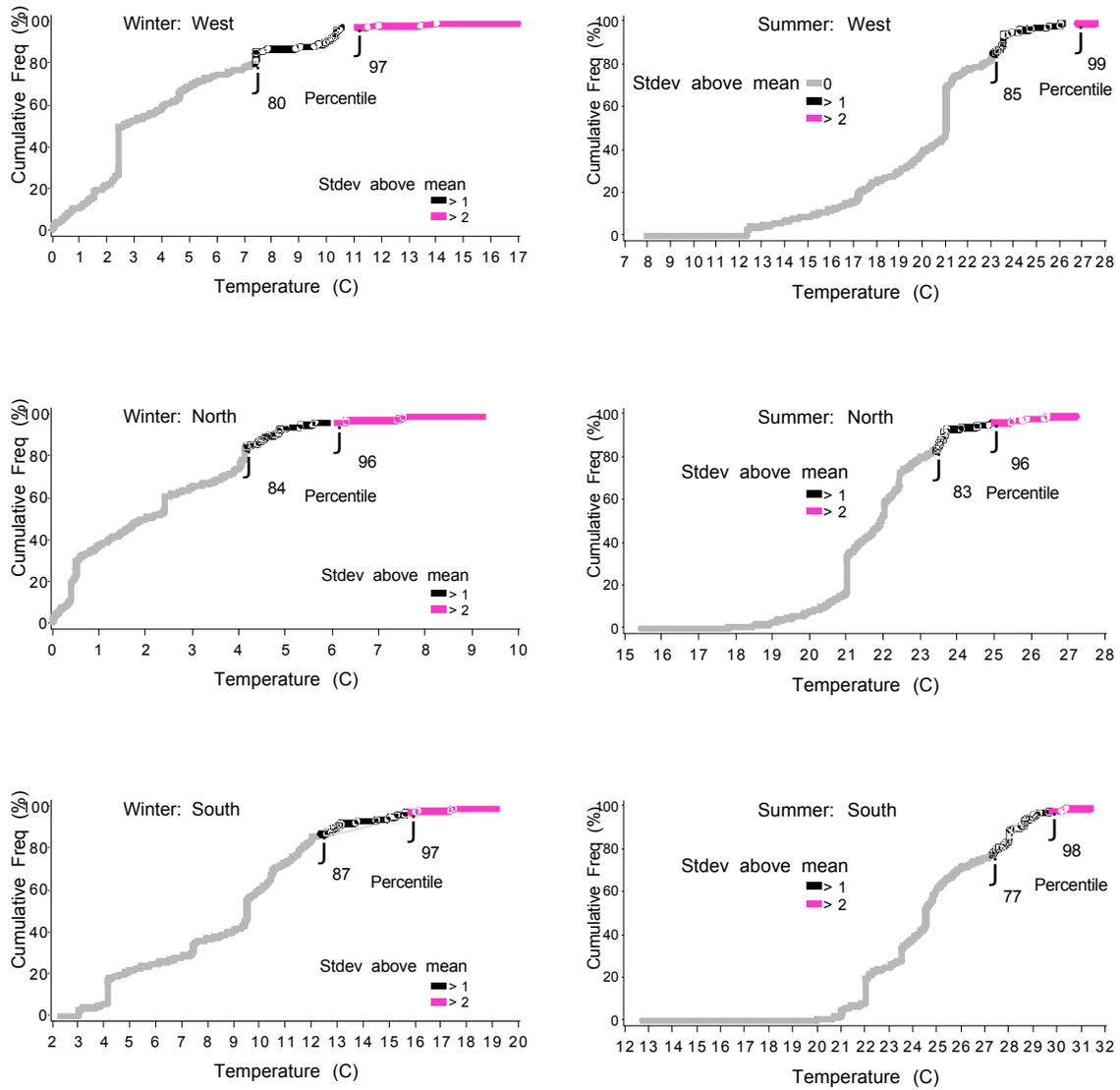


Figure 24.3. Cumulative frequency of water temperature in streams and rivers of forested counties in the United States, 1991 to 2000. Percentiles for counties one and two standard deviations above the mean are identified to assess upper thresholds for respective regions and seasons.

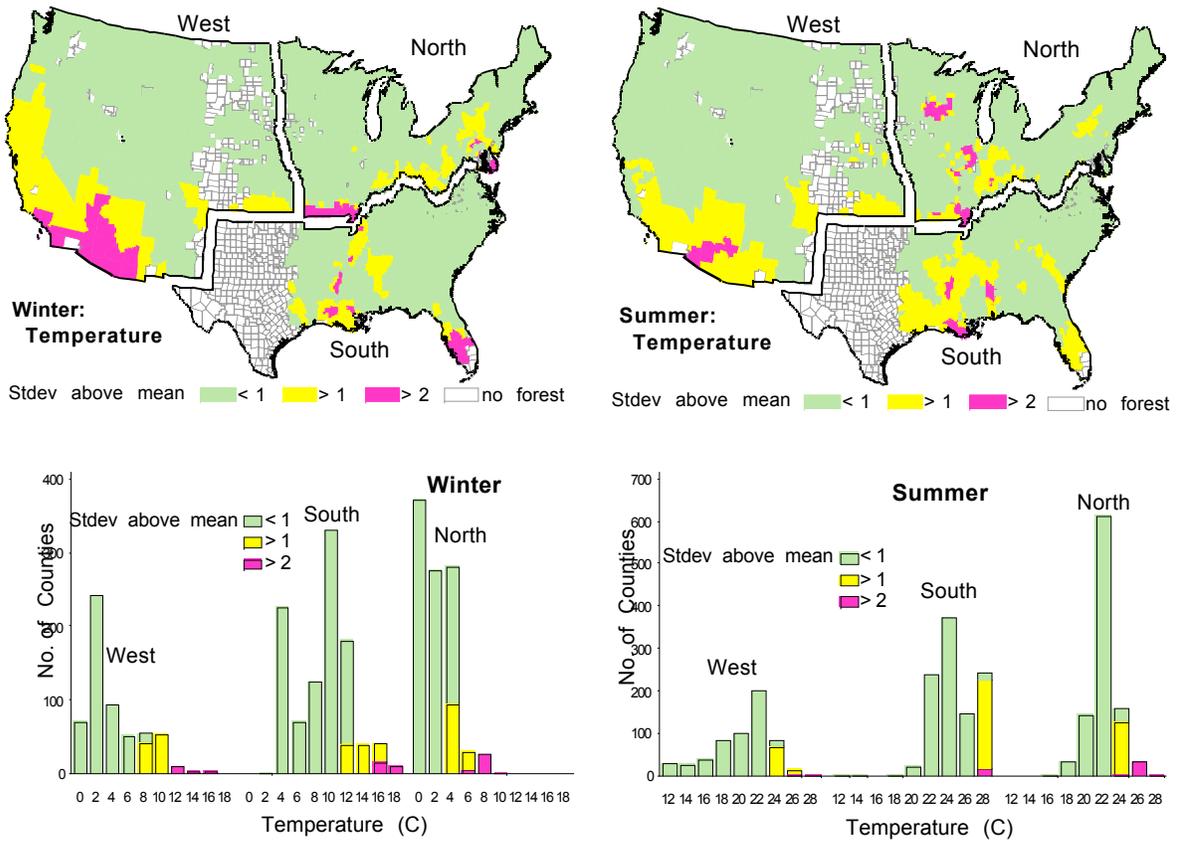


Figure 24.4. Distribution and location of counties one and two standard deviations above mean water temperature in streams and rivers of forested counties for respective regions and seasons, 1991 to 2000.

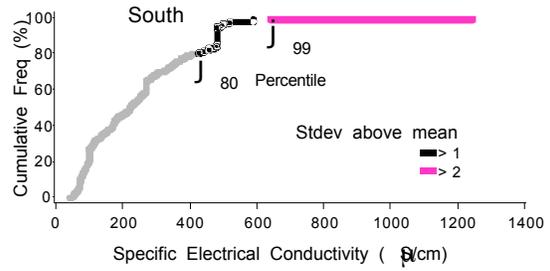
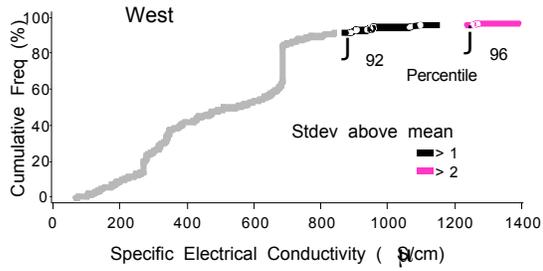
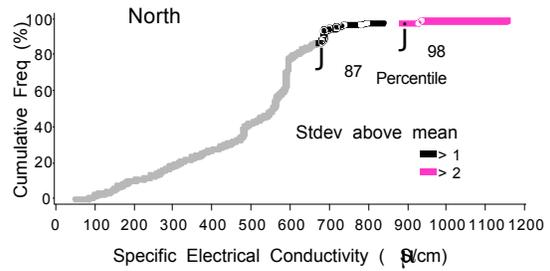


Figure 24.5. Cumulative frequency of specific electrical conductivity (adjusted to 25 °C ) in streams and rivers of forested counties in the United States, 1991 to 2000. Percentiles for counties one and two standard deviations above the mean are identified to assess upper thresholds for respective regions.



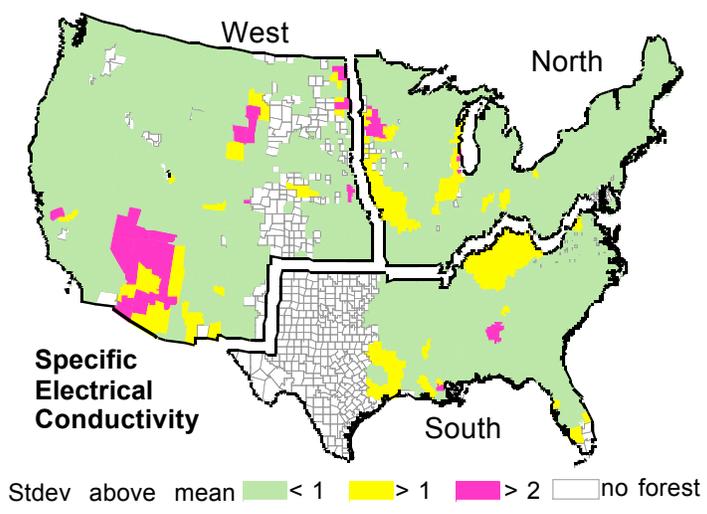
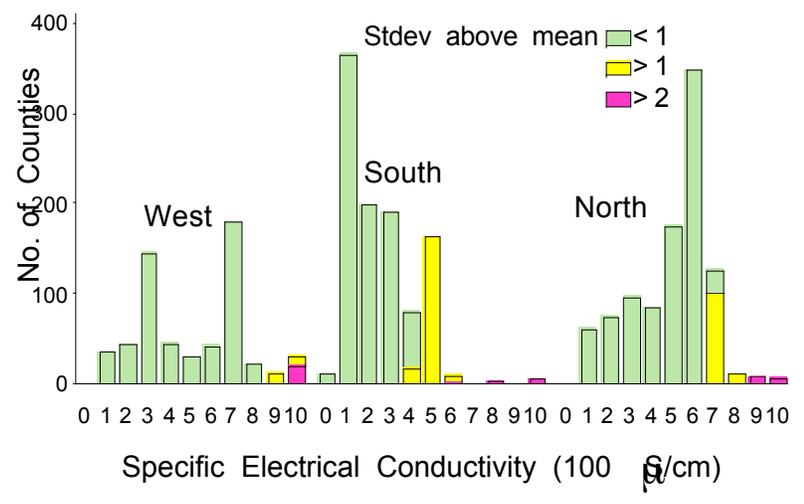


Figure 24.6. Distribution and location of counties one and two standard deviations above mean specific electrical conductivity in streams and rivers of forested counties for respective regions, 1991 to 2000.



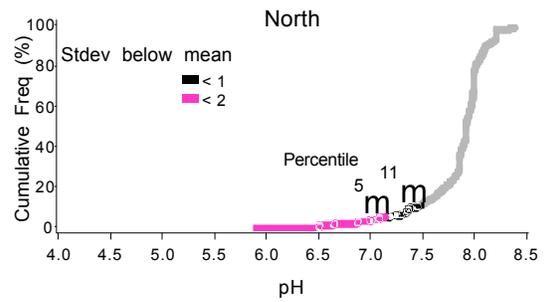
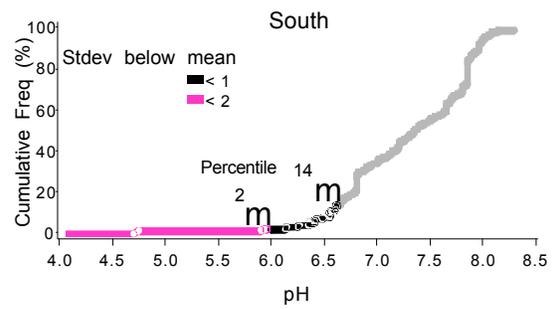
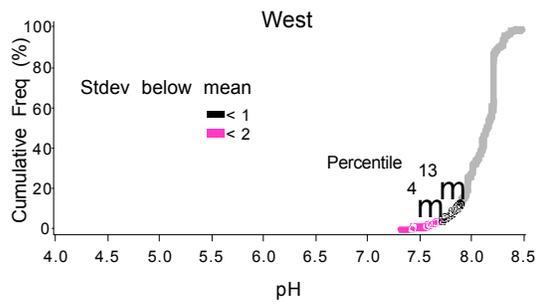


Figure 24.7. Cumulative frequency of pH in streams and rivers of forested counties in the United States, 1991 to 2000. Percentiles for counties one and two standard deviations below the mean are identified to assess lower thresholds for respective regions.

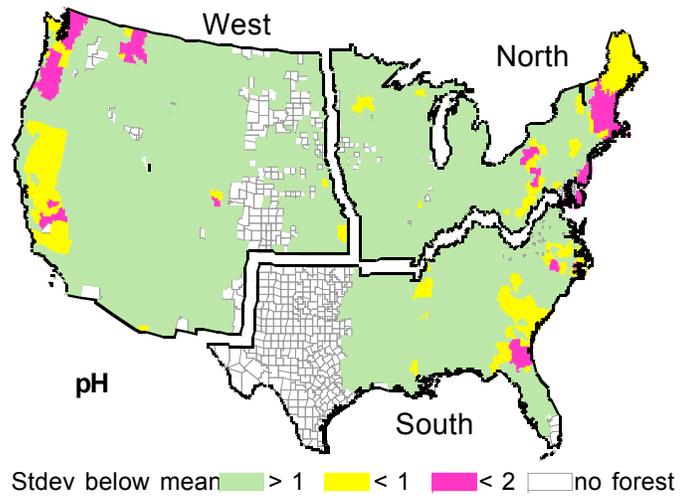
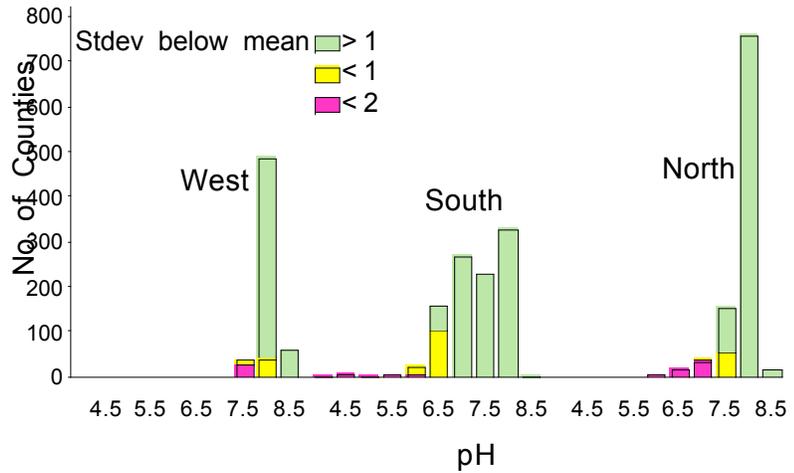


Figure 24.8. Distribution and location of counties one and two standard deviations below mean pH in streams or rivers of forested counties for respective region, 1991 to 2000.



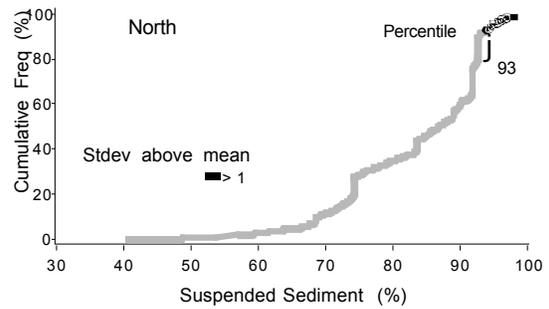
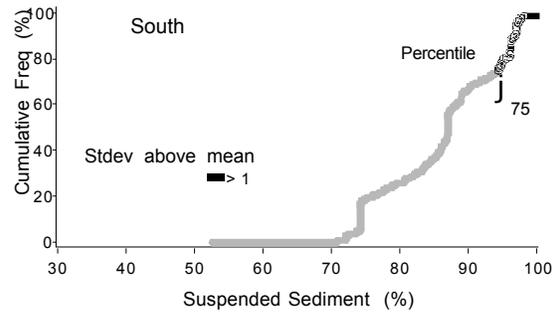
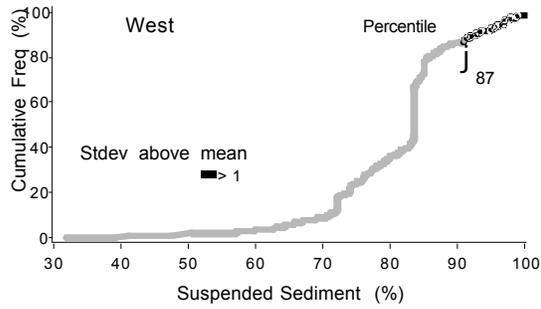


Figure 24.9. Cumulative frequency of suspended sediment in streams and rivers of forested counties in the United States, 1991 to 2000. Percentiles for counties one standard deviation above the mean are identified to assess upper threshold for respective regions.

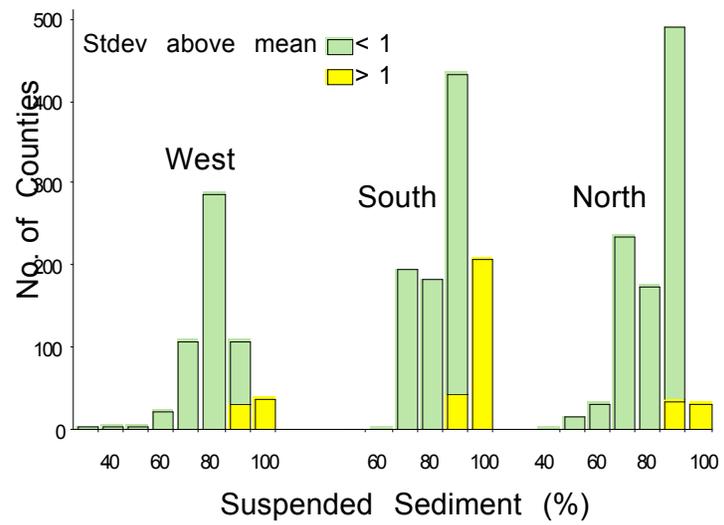
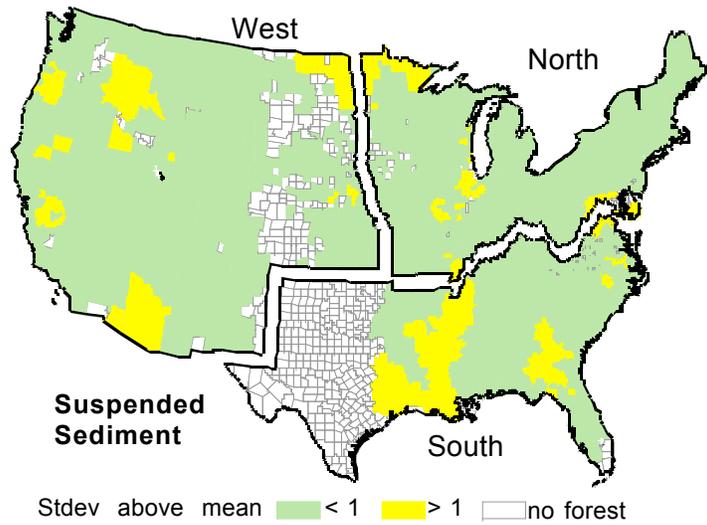


Figure 24.10. Distribution and location of counties one standard deviation above mean suspended sediment in streams and rivers of forested counties for respective regions, 1991 to 2000.