

## Why Is Soil Chemistry Important?

The soil quality indicator was initially developed as a tool for assessing the current status of forest soil resources and predicting potential changes in soil properties. Soil chemistry data can be used to diagnose tree vigor and document the deposition of atmospheric pollutants (e.g., acid rain). This chapter focuses on two chemical properties of the soil: soil pH and effective cation exchange capacity (ECEC).

Soil pH is considered by some to be the single most diagnostic chemical measurement of the soil (McBride 1994). Soil pH is responsive to air pollution and precipitation chemistry (Bailey and others 2005). In addition to its rare direct effects on roots and soil microorganisms, soil pH also influences metal toxicity, micronutrient availability, ion exchange, microbial activity, reduction/oxidation reactions, and soil aggregate stability (McBride 1994). For all of these reasons, soil pH is an important indicator for the maintenance of forest ecosystem health and vitality.

ECEC is a measure of the storage capacity of soils for key nutrients such as potassium, magnesium, and calcium and also for the key acid-generating element in soils, aluminum. Clay minerals and organic matter are the soil components chiefly responsible for soil ECEC. Soils with high ECEC can store large amounts of cationic nutrients [sodium ( $\text{Na}^+$ ), potassium ( $\text{K}^+$ ), magnesium ( $\text{Mg}^{2+}$ ), and calcium ( $\text{Ca}^{2+}$ )] or acid-generating cations [aluminum ( $\text{Al}^{3+}$ ) and hydrogen ( $\text{H}^+$ )], depending on soil pH. The total amount of exchangeable cations that a soil can hold is referred to as the ECEC, while the percent base saturation is the total amount of basic cations ( $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Mg}^{2+}$ , and  $\text{Ca}^{2+}$ ) expressed as a percentage of the total cation exchange capacity of the soil (base cations plus exchangeable  $\text{Al}^{3+}$ ) (Potash and Phosphate Institute 1995). It is generally held that increases in percent base saturation are correlated with improved forest soil fertility (Pritchett and Fisher 1987). In the Forest Inventory and Analysis (FIA) protocol, ECEC is calculated as the sum of the amounts of exchangeable bases ( $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Mg}^{2+}$ , and  $\text{Ca}^{2+}$ ) and  $\text{Al}^{3+}$  in soils and is measured at the natural soil pH. The measurement unit is centimoles of cation charge per unit mass of soil ( $\text{cmol}(+)/\text{kg}$ ).

## CRITERION 4—

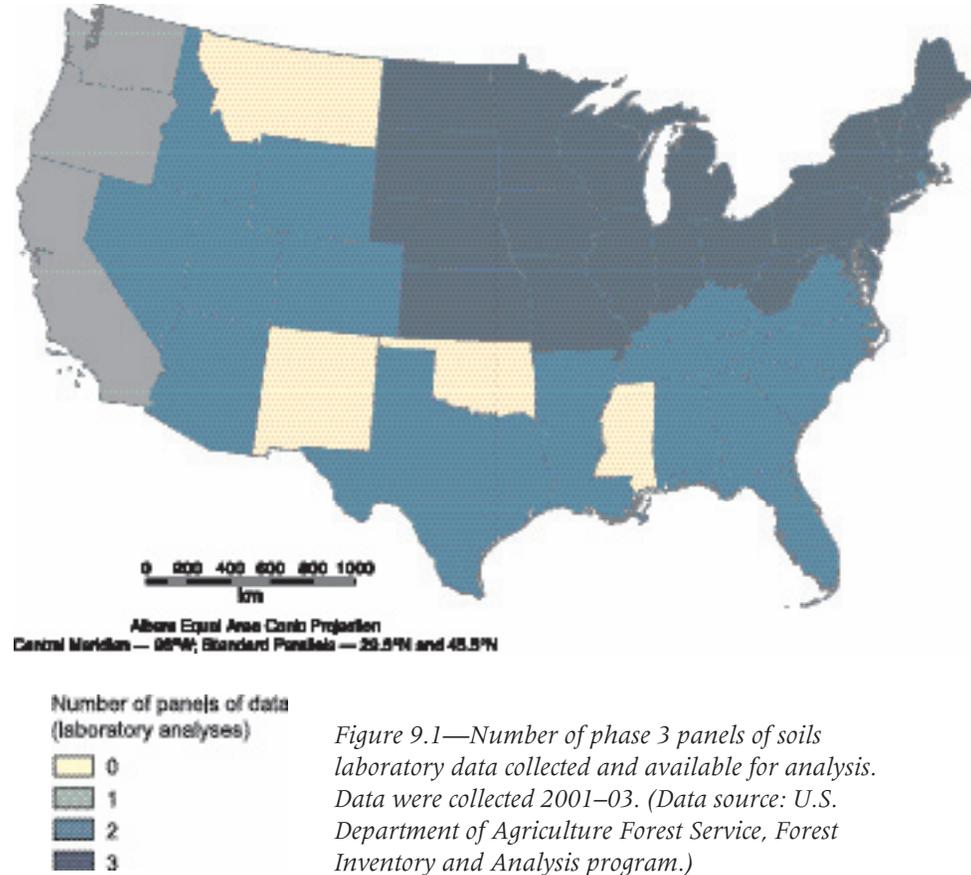
# Chapter 9. Chemical Properties of Forest Soils

CHARLES H. PERRY AND  
MICHAEL C. AMACHER

## Methods

Soil samples for chemical analysis are collected as part of the FIA soil quality indicator. Between 2001 and 2003, samples were collected in most of the continental United States (fig. 9.1). The sample size will increase as work in these States is completed and additional States are inventoried. The changing sample size and refinement of the database management and estimation algorithms together suggest that the results presented here should be considered preliminary.

One mineral soil sample was collected on each phase 3 plot according to well-documented protocols<sup>1</sup> and sent to regional laboratories for chemical analysis (U.S. Department of Agriculture Forest Service 2006). Additional details on field measurements, laboratory processing, and estimation procedures are available<sup>2</sup> (O'Neill and others 2005).



<sup>1</sup> U.S. Department of Agriculture, Forest Service. 2002. Forest inventory and analysis national core field guide: field data collection procedures for phase 3 plots, version 1.7. U.S. Department of Agriculture, Forest Service, Washington Office. Internal report. Vol. 2. On file with: U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis, Rosslyn Plaza, 1620 North Kent Street, Arlington, VA 22209.

<sup>2</sup> The current version of the *Forest Inventory and Analysis National Core Field Guide* is available online at: <http://fia.fs.fed.us/library/field-guides-methods-proc/>.

Soil pH and ECEC were determined for each plot by queries to the soils database. Only the top 10 cm of mineral soil were evaluated. Spatially explicit comma-delimited files were exported from the database and imported into ArcMap (Harlow and others 2004). For mapping purposes, soil chemical properties were assigned to hexagons developed by the Environmental Monitoring and Assessment Program (EMAP) of the U.S. Environmental Protection Agency (White and others 1992). Approximately 90 percent of the hexagons had only one measurement in them; the remaining 105 hexagons had two observations, which were averaged. Each hexagon has an area of approximately 648 km<sup>2</sup>, and their center points are roughly 27 km apart. Numeric data were imported into R (Venables and others 2005) for statistical analysis and plotting. Results for soil pH were aggregated into classes developed by Amacher and others (in press).

### What Do the Data Show?

Forest soil pH in the United States tends toward the acidic (fig. 9.2). This can affect the

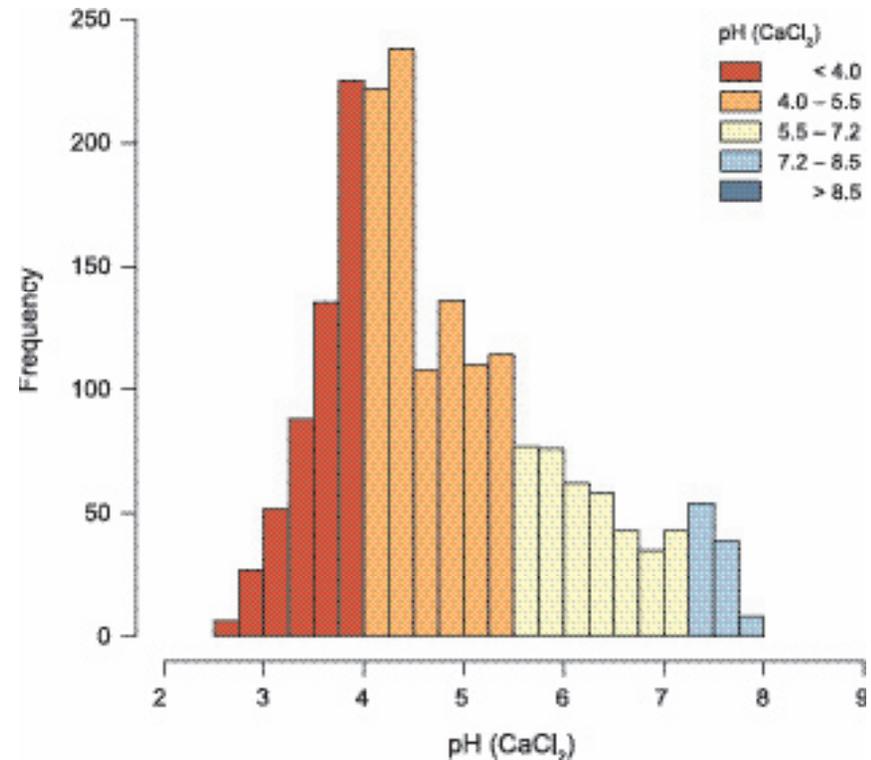


Figure 9.2—Distribution of observations of soil pH in the top 10 cm of soil (2001–03). (75<sup>th</sup> percentile = 5.5, mean = 4.8, median = 4.5, 25<sup>th</sup> percentile = 4.0.) The colors represent the same pH levels they represent in figure 9.3. (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis program.)

growth of acid-intolerant plant species (table 9.1). Eastern soils tend to be more acidic than their western counterparts (fig. 9.3). The spatial distribution of low pH values coincides with previous observations of acid deposition (see National Atmospheric Deposition Program 2005). Future research will investigate whether there is any causal relationship between atmospheric deposition and low soil pH. Soils of the arid Southwest are generally alkaline (fig. 9.3) because low precipitation allows for the accumulation of acid-neutralizing carbonate minerals in the soil profile.

**Table 9.1—Soil pH with associated interpretations<sup>a</sup>**

Soil pH	Interpretation
< 4.0	Strongly acid – only the most acid tolerant plants can grow in this pH range and then only if organic matter levels are high enough to mitigate high levels of extractable Al and other metals
4.0 – 5.5	Moderately acid – growth of acid intolerant plants is affected depending on levels of extractable Al, Mn, and other metals
5.5 – 7.2	Slightly acid to near neutral – optimum for many plant species
7.2 – 8.5	Slightly to moderately alkaline – optimum for many plant species except those that prefer acid soils, possible deficiencies of available P and some metals (e.g., Zn)
> 8.5	Strongly alkaline – preferred by plants adapted to this pH range, possible B and other oxyanion toxicities

<sup>a</sup>Amacher and others (in press).

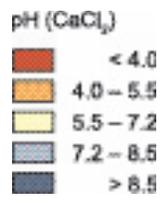
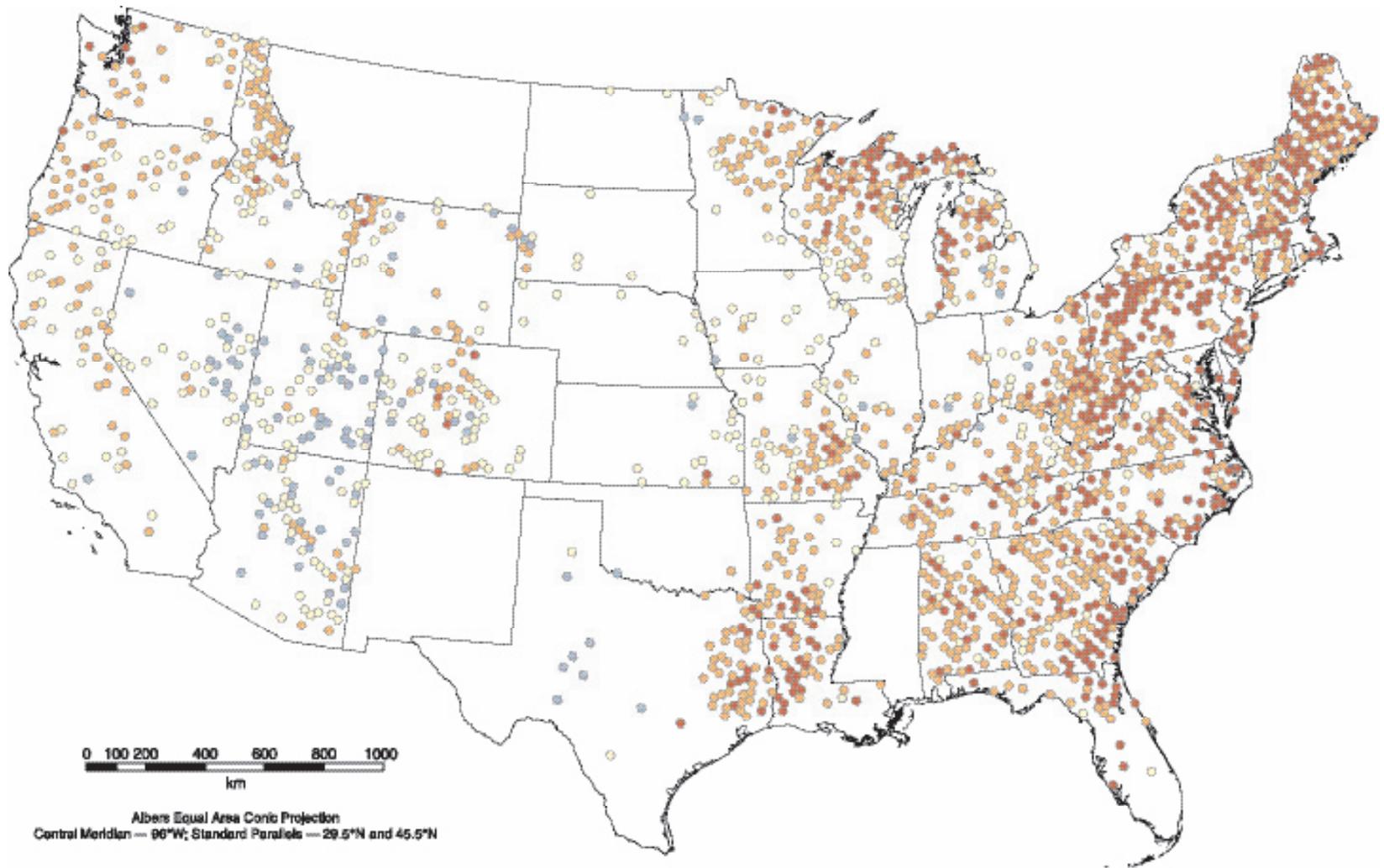


Figure 9.3—National map of observations of soil pH in the top 10 cm of soil (2001–03) by Environmental Monitoring and Assessment Program (EMAP) hexagon (White and others 1992). Soil pH was measured in a calcium chloride (CaCl<sub>2</sub>) solution. (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis program.)



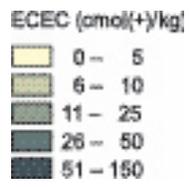
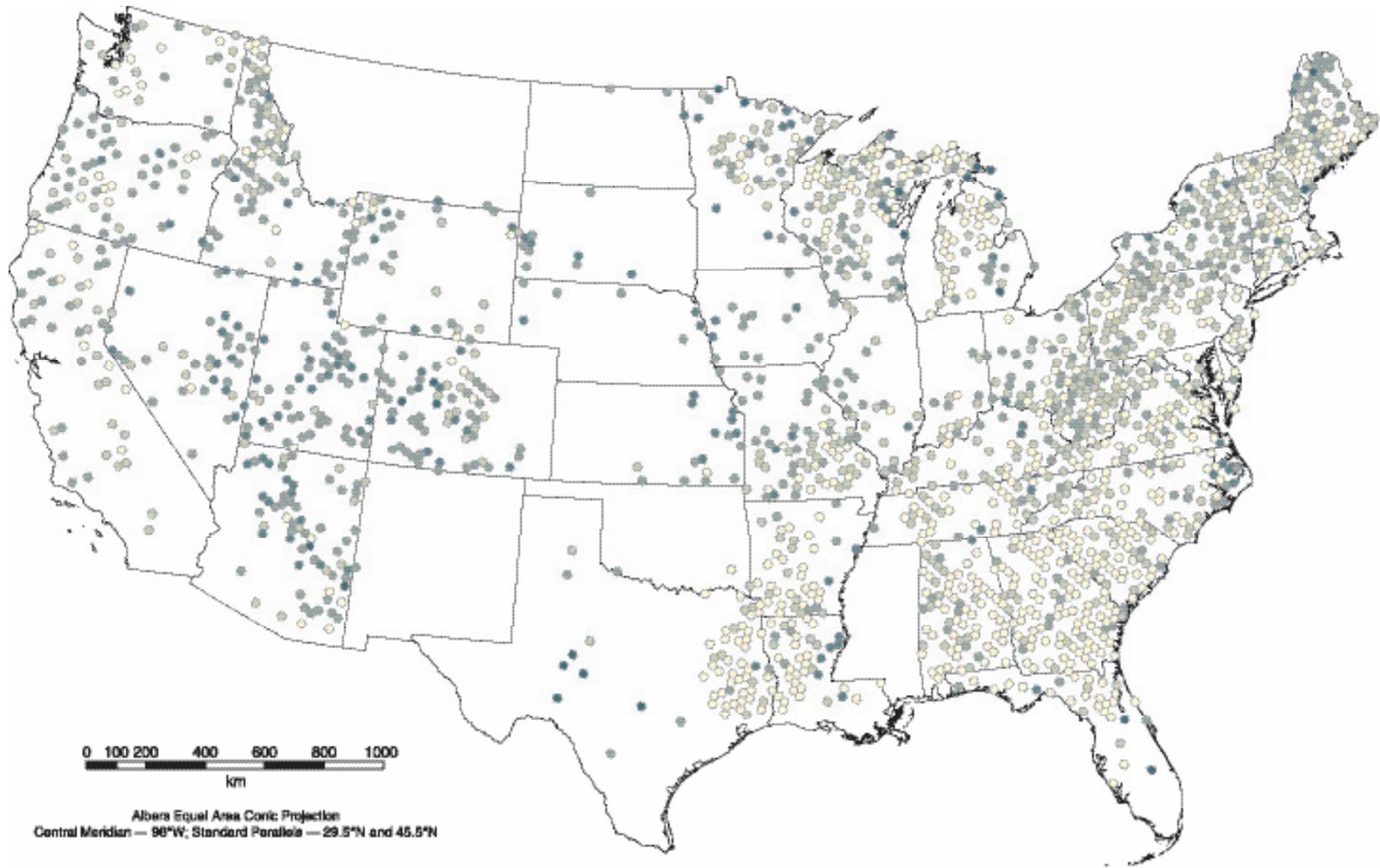


Figure 9.5—Effective cation exchange capacity (ECEC) in the top 10 cm of soil (2001–03) by Environmental Monitoring and Assessment Program (EMAP) hexagon. (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis program.)

## Literature Cited

- Amacher, M.C.; O'Neill, K.P.; Perry, C.H. [In press]. Soil vital signs: a new soil quality index (SQI) for assessing forest soil health. Res. pap. RMRS–RP. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.
- Bailey, S.W.; Horsley, S.B.; Long, R.P. 2005. Thirty years of change in forest soils of the Allegheny Plateau, Pennsylvania. *Soil Science Society of America Journal*. 69(3): 681-690.
- Harlow, M.; Pfaff, R.; Minami, M. [and others]. 2004. Using ArcMap: ArcGIS 9. Redlands, CA: ESRI Press. 598 p.
- McBride, M.B. 1994. *Environmental chemistry of soils*. New York: Oxford University Press. 406 p.
- National Atmospheric Deposition Program. 2005. Isopleth maps. <http://nadp.sws.uiuc.edu/isopleths/> [Date accessed: June 24, 2005].
- O'Neill, K.P.; Amacher, M.C.; Perry, C.H. 2005. Soils as an indicator of forest health: a guide to the collection, analysis, and interpretation of soil indicator data in the Forest Inventory and Analysis program. Gen. Tech. Rep. NC-258. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 53 p.
- Potash and Phosphate Institute. 1995. *Soil fertility manual*. Atlanta: Potash and Phosphate Institute. 116 p.
- Pritchett, W.L.; Fisher, R.F. 1987. *Properties and management of forest soils*. 2<sup>d</sup> ed. New York: John Wiley. 494 p.
- U.S. Department of Agriculture, Forest Service. 2006. Forest inventory and analysis at the North Central Research Station: national programs—soil quality: analysis <http://www.ncrs.fs.fed.us/4801/national-programs/indicators/soils/analysis/> [Date accessed: April 25, 2006].
- Venables W.N.; Smith D.M.; the R Development Core Team. 2005. An introduction to R, notes on R: a programming environment for data analysis and graphics. Version 2.1.1 (2005-06-20). <http://www.r-project.org/> [Date accessed: June 21, 2005]. 90 p.
- White, D.; Kimerling, A.J.; Overton, W.S. 1992. Cartographic and geometric components of a global sampling design for environmental monitoring. *Cartography and Geographic Information Systems*. 19(1): 5-21.