828 Davis Rd., League City, TX 77573
Toll-free: 888-306-LAND (5263) **Phone:** 609-412-0555
info@landviser.com **Web:** www.landviser.com
Blogs / eLibrary / Support: www.landviser.net

THEORY of FOUR-ELECTRODE RESISTIVITY/CONDUCTIVITY METHOD

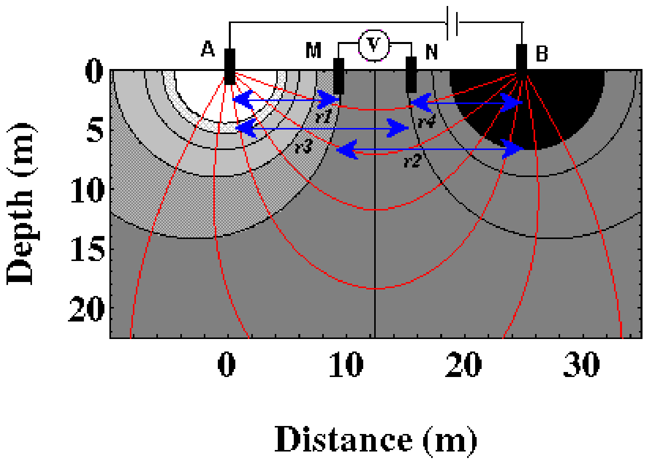
The geophysical devices of LandMapper® series can be used to measure **electrical resistivity** or **conductivity** of soils for fast non-destructive mapping of agricultural fields, construction and remediation sites, and similar applications. Our devices are **very versatile** and can be applied on soil surface, in wells/pits, or in soil and other semisolid laboratory samples. In a typical setting the **four-electrode probe** is placed on the soil surface and electrical resistivity value is read from the digital display. Device allows to measure electrical resistivity of the surface soil layer with the depth set by varying the size of the four-electrode probe. The equipment is developed in Russia by ASTRO GROUP, OOO for Landviser, LLC, USA and based on more than 30 years of scientific research of Russian and American soil physicists. Prototype of the LandMapper® was developed and used for soil studies in Russia, Ukraine, USA, Canada, Philippines and Chili (Pozdnyakov et al., 1996; Pozdnyakova et al., 1996; Pozdnyakov, 2001; Pozdnyakova et al., 2001).

The first attempt to measure electrical resistivity of soils was made at the end of the nineteenth century with the two-electrode technique. Whitney et al. (1897), Gardner (1898), and Briggs (1899) developed relationships between soil electrical resistivity and soil water content, temperature, and salt content. The two-electrode method measures the sum of both soil resistivity and the contact resistivity between the electrode and soil. The latter is very erratic and unpredictable.

Wenner (1915) based on the work of Schlumberger suggested that a linear array of four equally spaced electrodes would minimize soil-electrode contact problems if potential-measuring and current-induced electrodes are separated in space. Since then all the electrical resistivity methods applied in geophysics and soil science are still based on the standard **four-electrode principle**.

Method of four-electrode probe has been used in soil practices since 1931 for evaluating soil water content and salinity under field conditions (McCorkle, 1931; Edlefsen and Anderson, 1941; Rhoades and Ingvalson, 1971). Halvorson and Rhoades (1976) applied a four-electrode probe in the Wenner configuration to locate saline seeps on croplands in USA and Canada. Austin and Rhoades (1979) developed and introduced a compact four-electrode salinity sensor into routine agricultural practices. A special soil salinity probe, which utilized the same four-electrode principle, was also designed for bore-hole measurements and/or for permanent installations in soils for infiltration and salinity monitoring (Rhoades and Schilfgaarde, 1976; Rhoades, 1979). An electrical cell used to measure electrical conductivity of soil samples, pastes, and suspensions, was also developed based on four-electrode principle (Gupta and Hanks, 1972). The advantages of electrical conductivity measurements for evaluation of soil salinity led to development of soil salinity classifications using electrical conductivities of soil pastes and suspensions (Richards et al., 1956). Relationships between electrical conductivity measured in-situ with four-electrode probe and conductivity of soil solution or saturated soil paste were developed (Nadler, 1982; Rhoades et al., 1989). The method of four-electrode probe was also used for evaluation of some other soil properties, such as soil water content (Edlefsen and Anderson, 1941; Kirkham and Taylor, 1949); structure (Nadler, 1991); bulk density, porosity, and texture (Banton et al., 1997); stone content and pollution by oil-mining facilities (Pozdnyakova, 1999), locations of the burial places in archaeology and criminology (Pitruk et al., 1997; Butler and Llopis, 1997), etc. Recently measurements of soil electrical resistivity were coupled with geostatistical methods to develop accurate soil maps (Pozdnyakova and Zhang, 1999; Butler, 2001).

Thus, the method of measuring electrical resistivity or conductivity using four-electrode probe has been applied in geology and soil science for almost a century and the theory of the method is well developed. However, the new advantages in electronics technology allowed us to develop a mechanism, which automatically accounts for the spontaneous potentials arising at the electrodes and considerably improves measurements accuracy.



Our equipment utilizes well-known four-electrode principle to measure electrical resistivity or conductivity, as shown in the figure. LandMapper® measures potential difference ($\Delta\varphi$), which arises between two electrodes (M and N), when electrical current (*I*) is applied to other two electrodes (A and B).

In theory, electrical resistivity (*ER*) of a material is defined as follows:

$$ER = \frac{A\Delta\varphi}{LI} \qquad [1]$$

where *L* is the length of a uniform conductor with a cross-sectional area *A*. A/L is a geometrical coefficient (K), which is easily calculated for different in-situ electrode arrangements and laboratory conductivity cells.

LandMapper® calculates electrical resistivity using formula:

$$ER = K\frac{\Delta\varphi}{I} \qquad [2]$$

The direct digital output of the device is electrical resistivity in Ohm m. Those can be converted into electrical conductivity (S/m) by using reciprocal of the measured resistivity:

$$EC = \frac{1}{ER} \qquad [3]$$

Thus, the measured results may as well be presented in convenient for US soil scientists form of soil electrical conductivity (EC).

Coefficient K in Eq. [2] is geometrical factor depending on the distances among the electrodes AMNB. The vast majority of the 4-electrode arrangements (arrays) employed in geological and soil exploration is linear central-symmetric arrays similar to one shown in the figure above. In such arrays the potential-measuring MN electrodes are placed between A and B electrodes and AM=NB. The coefficient K for such arrays is calculated with formula:

$$K = \pi\frac{[AM]\cdot[AN]}{[MN]} \qquad [4]$$

where AM, AN, and MN are respective distances between electrodes measured in meters.

The depth of the measurement depends on the electrical resistivity of the soil as well as on the geometry on the four-electrode probe. For the probes in Wenner configuration (equally spaced, central symmetric, AM=MN=NB=*a*), which are supplied with the LandMapper®, the depth of the investigation is approximately equal to electrode spacing (***a***) for most soils (Barker, 1989). K coefficient for Wenner arrays is calculated as:

$$K = 2\pi a$$

LandMapper® is typically supplied with one four-electrode probe in Wenner configuration and coefficient K (K1) preset in the device memory. Users can order custom-made probes from us that can be set for different distances among electrodes, in which case the coefficients K will be calculated for the supplied probes and entered into device memory prior to shipping. However, if users wish to design their own probes for mapping or for measuring electrical resistivity in soil pits, columns, samples, or conducting 2D imaging of soil subsurface based on electrical resistivity, they will need to calculate their own coefficients K and enter them into device memory. The clear instructions and table provide formulas for calculating geometric factors K for practically any possible four-electrode configuration used for measuring electrical resistivity from soil surface (Zdanov and Keller, 1994). LandMapper® ERM-01 can only be used with central-symmetric electrode arrays and cells, while ERM-02 can utilize any possible electrode arrangements.

REFERENCES

Austin, R.S., and J.D. Rhoades. 1979. *A compact, low-cost circuit for reading four-electrode salinity sensors.* Soil Sci. Soc. Am. J. 43:808-809.

Banton, O., M. -K. Seguin, and M. -A. Cimon. 1997. *Mapping field-scale physical properties of soil with electrical resistivity.* Soil Sci. Soc. Am. J. 61:1010-1017.

Barker, R.D. 1989. *Depth of investigation of collinear symmetrical four-electrode arrays*. Geophysics. 54:1031-1037.

Briggs, L.J. 1899. *Electrical instruments for determining the moisture, temperature, and soluble salt content of soils*. U.S. Dept. Agr. Bul. 15.

Butler, H.C. 2001. *Spatial autocorrelation of soil electrical conductivity.* MS Thesis. Iowa State University, Ames, Iowa.

Butler, D. K., and J.L. Llopis. 1997. *Selected short stories on novel applications of near-surface geophysics*. The Leading Edge 16(Nov.): 1593-1600.

Edlefsen, N.E., and A.B.C. Anderson. 1941. *The four-electrode resistance method for measuring soil-moisture content under field conditions*. Soil Sci. 51:367-376.

Gardner, F.D. 1898. *The electrical method of moisture determination in soils: results and modifications in 1897.* U.S. Dept. Agr. Bul. 12.

Gupta, S.C. and R.J. Hanks. 1972. *Influence of water content on electrical conductivity of the soil*. Soil Sci. Soc. Am. Proc. 36:855-857.

Halvorson, A. D., and J. D. Rhoades. 1976. *Field mapping soil conductivity to delineate dryland saline seeps with four-electrode technique.* Soil Sci. Soc. Am. J. 40:571-574.

Kirkham, D., and G. S. Taylor. 1949. *Some tests of a four-electrode probe for soil moisture measurements*. Soil Sci. Soc. Proc. 14:42-46.

McCorkle, W.H. 1931. *Determination of soil moisture by the method of multiple electrodes.* Tex. Agr. Exp. Sta. Bul. 426.

Nadler, A. 1981. *Field application of the four-electrode technique for determining soil solution conductivity*, Soil Sc. Amer. J. 45:30-34.

Nadler, A. 1991. *Effect of soil structure on bulk soil electrical conductivity (Eca) using the TDR and 4P techniques*. Soil Sci. 152:199-203.

Pitruk, A.P., O.G. Omelianuk, A.I. Pozdnyakov, and L.A. Pozdnyakova. 1997. *Application of electrical profiling for identification of burial places as subject of criminal origin* (in Russian). Scientific Research of Crime Expertise Center of Ministry of Internal Affairs "Problems of Crime Expertise and Expert Solutions", Moscow, 6:103-110 (published in Russian, English version available).

Pozdnyakov, A.I. 2001. *Polevaya electrofizika pochv (Field Soil Electrophysics).* MAIK "Nauka-Interpereodika", Moscow. 1-278 (in Russian).

Pozdnyakov, A.I, L.A. Pozdnyakova, and A.D. Pozdnyakova. 1996. *Stationary electrical fields in soils* (in Russian with English summary). KMK Scientific Press, Moscow, Russia. 1-358 (in Russian).

Pozdnyakova, L.A. 1999. *Electrical properties of soils*. Ph.D. Thesis. University of Wyoming, Laramie, WY.

Pozdnyakova, L., A. Pozdnyakov, and R. Zhang. 2001. *Application of geophysical methods to evaluate hydrology and soil properties in urban areas*. *Case study*. London, UK, Urban Water 3:205-216.

Pozdnyakova, L.A., A.I. Pozdnyakov., and L.O. Karpachevsky. 1996. *Study hydrology of valley agricultural landscapes with electrical resistance methods.* Proceeding of XXI Assembly European Geophysical Society, HS16 "The Hydrology of Small Agricultural Catchments", The Hague, Netherlands. 341-352.

Pozdnyakova, L., and R. Zhang. 1999. *Geostatistical analyses of soil salinity in a large field.* Kluwer Academic Publishers, The Netherlands. Precision Agriculture **1**(2):153-165.

Rhoades, J.D. 1979. *Inexpensive four-electrode probe for monitoring soil salinity*. Soil Sci. Soc. Amer. J. 43:817-818.

Rhoades, J.D. 1993. *Electrical conductivity methods for measuring and mapping soil salinity*. Adv. Agron. 46:201-251.

Rhoades, J. D., N. A. Manteghi, P. J. Shouse, and W. J. Alves. 1989. *Estimating soil salinity from saturated soil-paste electrical conductivity.* Soil Sci. Soc. Am. J. 53:428-433.

Rhoades, J. D., and R. D. Ingvalson. 1971. *Determining salinity in field soils with soil resistance measurements.* Soil Sci. Soc. Amer. Proc. 35:54-60.

Rhoades, J.D., and J. van Schilfgaarde. 1976. *An electrical conductivity probe for determining soil salinity.* Soil Sci. Soc. Am. J. 40:647-650.

Richards, L. A., C. A. Bower, and M. Fireman. 1956. *Tests for salinity and sodium status of soil and of irrigation water.* USDA Circular No 982. U. S. Govern. Print. Office. Washington, D.C. 1-19.

Wenner, F. 1915. *A method of measuring earth resistivity*. US. Dept. Com. Bur. Standards Sci. Paper 258.

Whitney, M., F.D. Gardner, and L.J. Briggs. 1897. *An electrical method of determining the moisture content of arable soil.* U.S. Dept. Agr. Bul. 6.

Zdanov M.S., and G.V. Keller. 1994. *The geoelectrical methods in geophysical exploration. Methods in geochemistry and geophysics.* Series. Volume 31., Elsevier. Amsterdam-London-New York-Tokyo.