

**DEVELOPMENT OF CONDUCTIVITY PROBE AND TEMPERATURE PROBE FOR
IN-SITU MEASUREMENTS IN HYDROLOGICAL STUDIES**

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**CENTRO DE APLICAÇÃO DE RADIOISÓTOPOS E DE RADIAÇÕES NA ENGENHARIA E
NA INDÚSTRIA – CARREI
ÁREA DE APLICAÇÕES NA PRESERVAÇÃO E APROVEITAMENTO DE RECURSOS NATURAIS**

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ABSTRACT

A conductivity probe and a temperature probe have been developed for in-situ measurements in various hydrological field studies.

The conductivity probe has platinum electrodes and is powered with two 12 volt batteries. The sensing element of the temperature probe consists of a resistor of high coefficient of temperature.

Response of the conductivity probe is measured in a milliamperemeter while the resistance of the thermistor is read by a digital meter.

The values of conductivity and temperature are derived from respective calibration.

The probes are prototype and their range of measurement can be improved depending upon the requirement of the field problem.

1 – INTRODUCTION

The present report describes the development, calibration and use of a conductivity probe and a temperature probe for variety of hydrological investigations dealing with ground water quality and pollution, aquifer interconnections and exploration of geothermal waters.

2 – CONDUCTIVITY PROBE

2.1 – General Description

A rapid determination of dissolved solids in ground water can be made by measuring the electrical conductance of water sample or by in-situ measurement by a conductivity probe. Electrical conductivity or specific electrical conductance is defined as the reciprocal of the resistance measured between opposite faces of a centimeter cube of the solution. The actual resistance, R, of the solution is measured in ohms. In general, use is made of the term conductance rather than its reciprocal, resistance, because it increases with salt concentration. The conductance, 1/R, is directly proportional to the cross sectional area A, inversely proportional to the length of the path L. Mathematically,

$$\frac{1}{R} \propto A \cdot \frac{1}{L} = K \frac{A}{L}$$

or

$$K = \frac{L}{A} \cdot \frac{1}{R} \cdot \frac{\text{cm}}{\text{cm}^2} \cdot \frac{1}{\text{ohm}} \quad \text{or} \quad \frac{\text{mho}}{\text{cm}}$$

where K is the electrical conductivity. The expression (L/A) is known as cell constant, and is expressed in reciprocal of centimeters. Because most natural waters have conductivity much less than one mho/cm, it is convenient to multiply the value of K by 1,000,000 and express the results in micromhos/cm.

Conductivity is a function of temperature; hence a standard temperature, usually 25°C , is specified in reporting the conductivity. Water solution of electrolytes have temperature coefficients of conductivity as high as 3%. The coefficient varies somewhat, depending upon the composition of the electrolyte.

When necessary, a temperature coefficient must be determined and a correction applied. This requires a series of conductivity and temperature measurements of the sample, over the required temperature range. The values of conductivity of standard electrolyte solutions are shown in Table-1⁽¹⁾, for purpose of reference.

Table 1
Electrical Conductivity of Standard Potassium Chloride Solution⁽¹⁾

Normality of Solution	Temperature $^{\circ}\text{C}$	Electrical Conductivity $\mu\text{mhos/cm}$
1	0	65176
	18	97838
	25	111342
0.1	0	7138
	18	11167
	25	12856
0.01	0	773.6
	18	1220.5
	25	1408.8
0.001	0	
	18	
	25	146.93

An approximate relation exists between electrical conductivity and concentration, for most natural waters⁽⁶⁾, in the range of 100 to 5000 $\mu\text{mhos/cm}$ at 25°C , leading to following conversions:

$$1 \text{ meq/l of cations} = 100 K \times 10^6$$

$$1 \text{ ppm} = 156 K \times 10^6$$

For measuring conductivity of $10 \mu\text{mhos/cm}$ or less, cell constants from 0.01 to 0.1 are appropriate. For conductivity greater than $10 \mu\text{mhos/cm}$, cell constants from 0.01 to 10 or greater may be used depending upon the type of waters to be investigated. In each case, geometry of electrodes can be chosen which will preferably give a cell resistance in the range of 500 to 50,000 ohms. This is the basis of selection of cell constants in Table-2.

Table II
Recommended Cell Constants for Various Conductivity Ranges

Range of Conductivity $\mu\text{mhos/cm}$	Cell Constant cm^{-1}
0.05 to 20	0.01
1 to 200	0.1
10 to 2000	1
100 to 20,000	10
1000 to 200,000	50

The conductivity probe described in this report has been designed for following objectives:

- to determine in-situ conductivity of water (i.e., water quality) in cased (perforated) and uncased ground water borings;
- to study changes of dissolved ion concentration/salinity/pollutant concentration in industrial waste seepage ponds;
- to locate regions of sub-surface inflows of different salinity into a lake or reservoir;
- to study stratification and mixing pattern (analogous to temperature measurements) of streams of different density in a lake or reservoir;
- to detect pollution of ground water in monitoring wells installed downstream of industrial waste retention ponds;
- to study exchange of ground water and river water;
- to study problems related to saline water intrusion;
- to determine depth and condition of casings in a boring.

Use of such probe in ground water borings, will give direct information of quality of ground water at different depths, and indirect/qualitative information of the geological strata penetrated by the boring (provided there is no prominent vertical flow in the boring).

All ground waters contain in varying concentrations salts, carried by dissolution of soluble materials in geologic strata through which they pass. The concentration of the dissolved materials increases significantly, consequent to the pollution of waters due to releases of industrial wastes in surface waters, or directly to ground. Based on the data of dissolved ion concentration (conductivity data), it is possible to classify various waters as summarised in Table 3.

Table III
Classification of Waters on the Basis of Conductivity

Type	Conductivity
Rain water	Very low
Water passing through igneous rocks	Very low
Water passing through sedimentary rocks	Medium
Alluvial streams or artificially recharged water	Low-medium
Normal or artesian spring water	Low-medium
Irrigation water	
Evaporating water	
Fertilizer and percolating water	
Arid zone water	
Poorly drained water	Medium-high
Waters of magmatic origin, mineralised thermal springs	Medium
Entrapped waters i.e., waters trapped in sedimentary rocks since geological times	High
Brakish waters	Medium-high
Polluted waters	High

In exploration and development of ground water, and in reuse of waters, the criteria of quality of water is of neraly equal importance to quantity. Quality limits of water supplies for drinking water, industrial purposes and irrigation, apply to ground water because of its extensive development for these purposes. An idea of quality of waters recommended for industrial and irrigation purposes, can be obtained from Tables 4⁽⁵⁾, and 5⁽⁸⁾.

Table IV
Suggested Water Quality Tolerances for Industrial Uses⁽⁵⁾

Industry or Use	Total Solids, ppm
Boiler Feed	50 - 3000
Brewing & Distilling	500 - 1000
Beverages	850
Confectionary	100
Ice	1300
Plastics	200
Paper & Pulp	200 - 300
Textiles	200

Table V
Quality Classification of Water for Irrigation⁽⁸⁾

Electrical Conductivity mho/cm at 25°C	
Excellent	250
Good	250 – 750
Permissible	750 – 2000
Doubtful	2000 – 3000
Unsuitable	3000

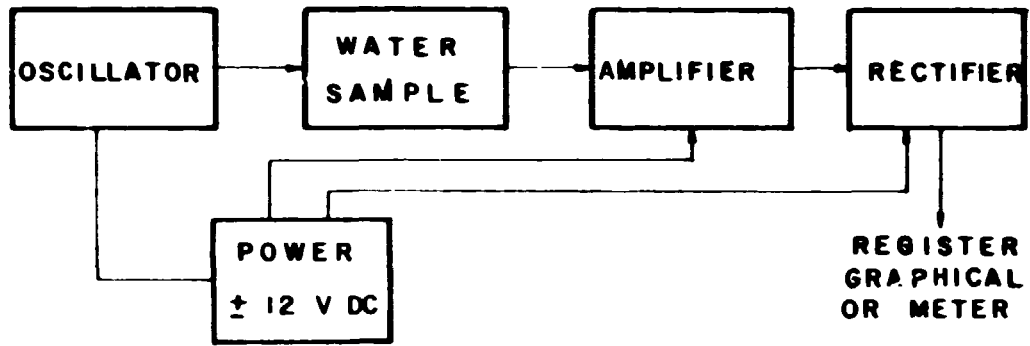
2.2 – Design and Calibration

The conductivity probe described in this report is meant for "in-situ" measurements in the field, as it is powered with two 12 Volt batteries. The probe consists of two electrodes of platinum, 1.5 cm in length and 3 mm in width, which are separated 1 cm apart. The electrodes are mounted on a teflon disc which is encapsulated inside a P.V.C. tube of 21 mm internal diameter. The coaxial cable connected to the probe terminals permits measurement of conductivity of water upto 200 m depth.

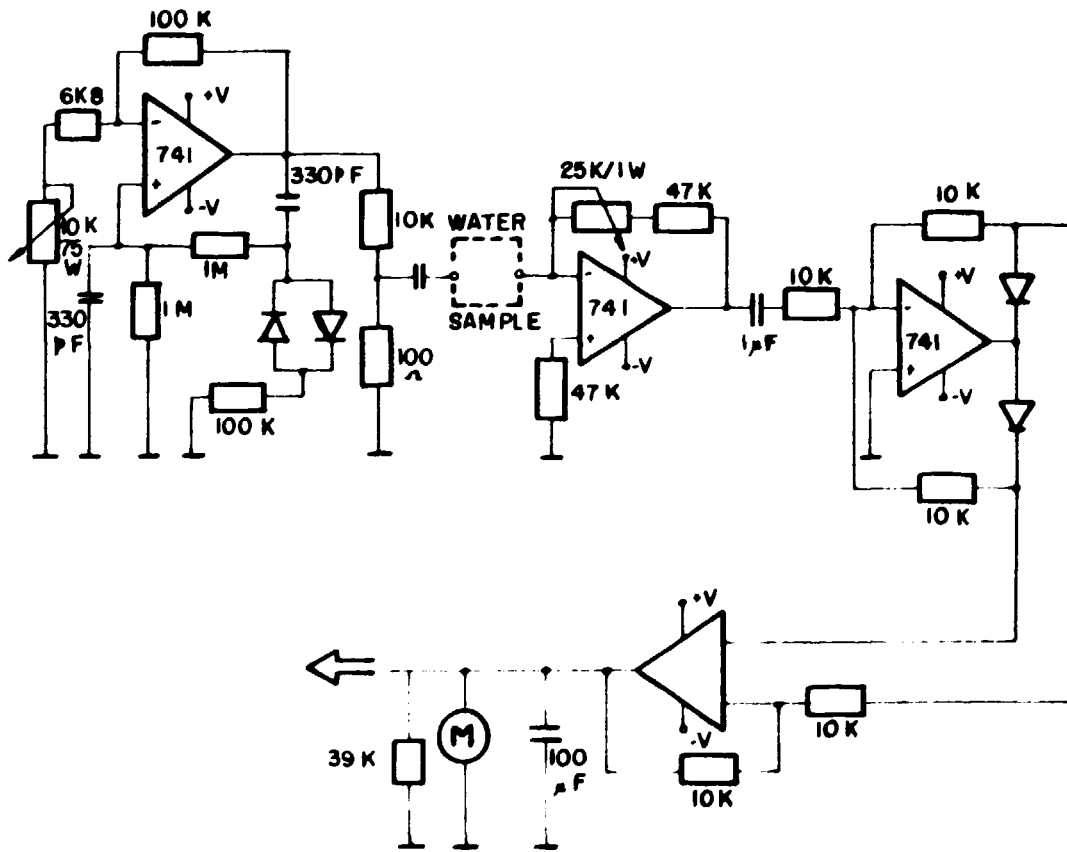
For calibration of the probe, series of standard solutions of potassium chloride were prepared. The conductivity of these solutions was measured in the laboratory by a conductivity meter of cell constant 0.087 cm^{-1} . The same solutions were used for calibrating the conductivity probe. The response of the probe was measured directly in a milliamperemeter. The circuit diagram of the electronic assembly employed in the meter is shown in Figure 1. The variation of the response of the conductivity probe with different solutions is shown in Table VI and Figure 2.

Table VI
Calibration of Conductivity Probe with Solutions of Different Conductivity

Concentration, N	Response of Conductivity Probe, mA	Conductivity $\mu\text{mhos/cm}$
0.0005	0.22	73.73
0.001	0.26	140.32
0.002	0.30	271.87
0.004	0.40	550.63
0.005	0.44	679.68
0.008	0.52	1080.97
0.01	0.56	1318.18
0.02	0.74	2521.74
0.04	0.92	4806.63
0.05	0.98	5638.93
0.08	> 1.0	8787.87



BLOCK DIAGRAM



ELECTRONIC CIRCUIT

Figure 1 - Circuit diagram of the electronic assembly used with conductivity probe.

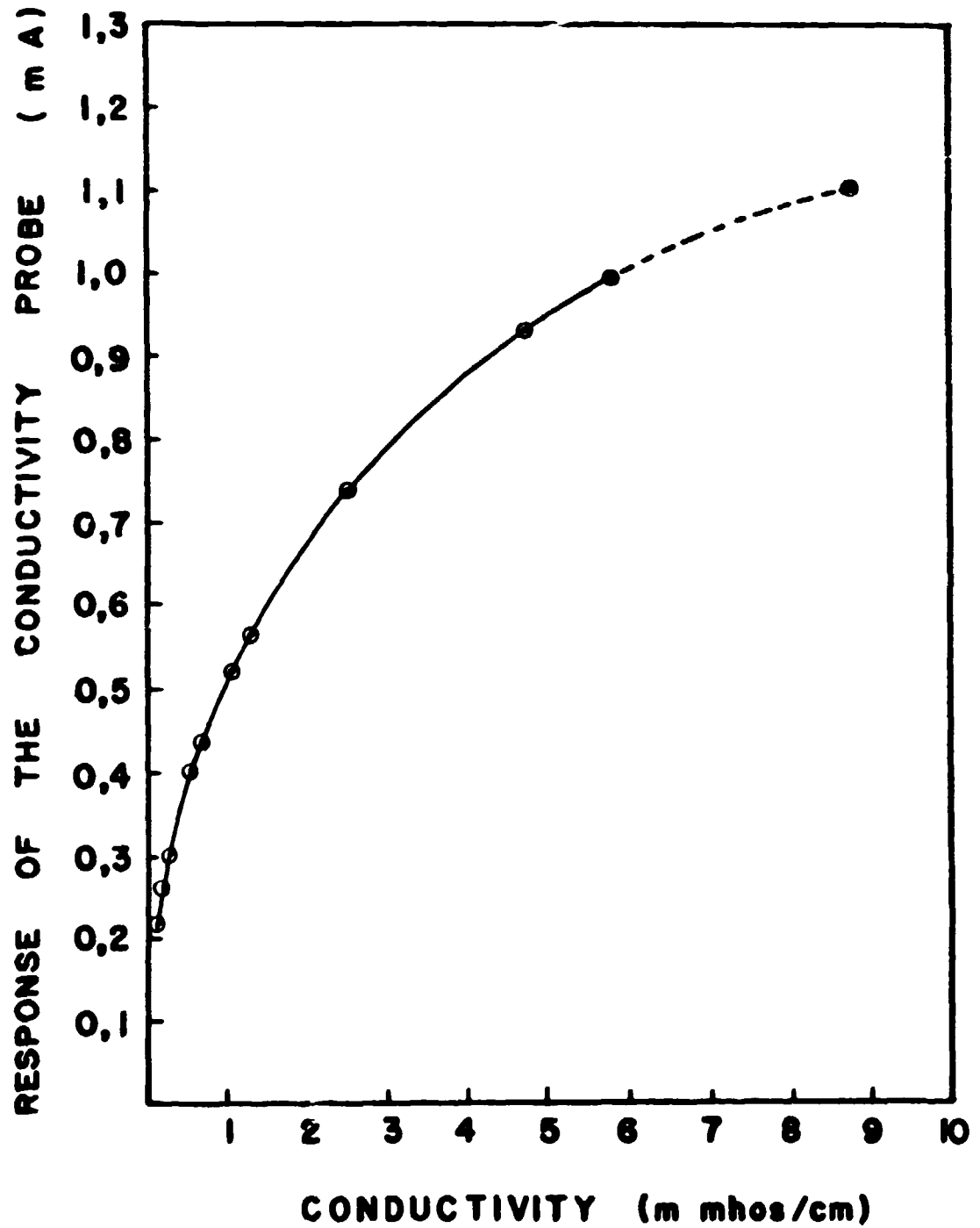


Figure 2 - Variation of response of conductivity probe with solution of different conductivity.

The variation of conductivity with temperature was studied by measuring the response of the probe in a standard KCl solution, maintained at various temperatures ranging from 5°C to 85°C. The measurement results are shown in Table VII.

Table VII
Calibration of Conductivity Probe at Various Temperatures
(Solution Used = 0.01 N KCl)

Temperature °C	Response of the Conductivity Probe mA
5	0.50
10	0.52
15	0.55
20	0.60
26	0.64
30	0.64
35	0.70
40	0.74
45	0.76
50	0.78
55	0.82
60	0.86
65	0.90
70	0.92
75	0.94
80	0.96
85	0.98

The variation of conductivity (Table VII and Figure 2) ranged from $0.9 \times 10^3 \mu\text{mhos/cm}$ at 5°C to $4.1 \times 10^3 \mu\text{mhos/cm}$ at 85°C. The temperature coefficient of conductivity measured by the probe was found to be 1.25% °C. The reproducibility of the response of the probe was determined by fifteen measurements with standard KCl solution at 26°C. The variation of the response was within one division (0.02 mA) of the meter.

The conductivity probe is suitable for measurement of conductivity of waters upto 9000 $\mu\text{mhos/cm}$, but its range can be enhanced by suitable modifications of the electronic unit.

3 – TEMPERATURE PROBE

3.1 – General Description

One of the most conservative properties of ground water is temperature. Ground water with a temperature of few degrees C above average local temperature may be described as thermal. The heat, in all cases, comes from the rocks in contact with the water. The rocks, in turn, are heated by the heat flow from the interior of the earth to the surface. The heat gradient in upper few thousand metres of the crust, varies in its value from place to place with an average value generally quoted being 1°C for each 30 m depth or about 30°C for each kilometre. Occasionally the heat flow is more intense due to a near surface intrusion of hot magma, thus giving place to thermal anomalies. Such areas are, in most cases, recognizable by the occurrence of hot water commonly accompanied by high alteration of the surface rocks and soil. In all other and far more common cases, the rise of a few degrees upto a few tens of degrees in the temperature, is caused by the descent of ground water into deep rocks, heating of the water by the local heat gradient and later on ascent of the water to the surface. Cycling ground water commonly has high enough flowing rates to cool the terrain it passes, and as a result, cycling ground waters have local average surface temperatures, e.g. upto about 20°C . Water that occurs in geothermally normal areas with elevated temperatures, say above 28°C , has therefore slow flow rates or is even trapped.

It is thus possible to arrive at the estimate of the depth from which the geothermal waters ascend. For example, a spring of 30°C in a region with an average annual temperature of 19°C is therefore thermal by 12°C . With the normal heat gradient of 1°C for each 30 m depth, one obtains a minimum depth of $12 \times 30 = 360$ m. A spring of 60°C , in the same region, may accordingly ascend from a depth of $42 \times 30 = 1260$ m. Such depth estimate are to be regarded only as general, and are always based on the assumption of flow rates in the deep aquifer, that are low enough not to disturb the heat balance significantly.

Elevated temperatures may be used in hydrological studies as indicators of deep seated water, being all or in part, older than cycling meteoric waters. An interrelation of elevated temperatures with elevated salt contents, radon and radium concentrations and ancient carbon-14 ages, is often observed. To follow up studies of environmental isotopes in natural waters, it is recommended that temperature measurements, which are easiest and cheapest, be made along with for exploratory and more rewarding investigation.

In short, measurement of temperature of ground water can yield information on the following:

- possible interconnection of bodies of water (surface and ground waters);
- thermal burdens on water bodies due to release of effluents;
- exploration of geothermal waters and delineating zones of different temperatures in the geothermal field;
- recirculation pattern in lakes and reservoirs.

With particular reference to measurement of temperature for exploration of geothermal potential of Brazil, it can be said that very little is known about the vertical distribution of temperature beneath major tectonic units in the country. Only recently some data have become available. Even the existing data of measurements pertain to scattered points areally. Many measurements have been made in southeastern Brazil^(7,4,2) but vast areas in the western, central and northern parts of the country remain unexplored.

However, there do not seem to be areas of young volcanism or active tectonics in Brazil; hence, regions of very high geothermal gradients are absent in Brazil. The youngest volcanic activity has been 80-120 million years ago in the Paraná Basin, and one expects to encounter only low enthalpy hot water

systems. Latest data reported give a regional geothermal gradient of 30 to 40°C/Km for the Paraná Basin, in contrast to gradients of less than 20°C/Km for the Brazilian shield. Paraná Basin has highly permeable aquifers, impermeable cap rocks and suitable recharge zones. Conservative estimates⁽²⁾ reveal that these aquifers contain substantial quantities of waters in the temperature range 40 to 90°C and can be considered as low enthalpy geothermal system.

Area near Poços de Caldas shows evidence of past volcanic and magmatic activity in the form of hot springs. This area is located about 200 km north of the city of São Paulo, in the state of Minas Gerais, and covers a circular area of 30-40 km (minimum and maximum diameters). Information on chemical composition of these thermal springs, zone of thermalisation and associated geophysical data, can be studied to estimate temperature and size of the geothermal field and justify experimental drilling. There are numerous hot mineral springs in the area, with surface water temperatures in the range of 40-50°C. Although water at these temperature is not of commercial interest⁽³⁾, many experts believe there may be a large magmatic chamber fairly close to the surface. If so, this area could become a local source of energy for the mining and milling of the Poços de Caldas ores.

3.2 – Design and Calibration

The temperature probe has been developed for carrying out "in-situ" measurements of temperature required for many hydrological investigations.

The sensing element of the temperature probe consists of a resistor (negative temperature coefficient type PB 32D1) of high coefficient of temperature. The conductivity σ of the thermistor can be expressed by the following expression:

$$\sigma = n e \mu$$

where,

n = concentration of the charge carried

e = unit of electrical charge

μ = mobility of the charge carried

n and μ are directly dependent on temperature. The relation between resistance and temperature of the NTC thermistor can be approximated by the following expression;

$$R = A e^{B/T}$$

where, R is the value of resistance at T° absolute (K). A and B are constants of the thermistor. The value of the constant B can be evaluated by measurement of resistance at two temperatures T_1 and T_2 ;

$$R_1 = A e^{B/T_1} \text{ and } R_2 = A e^{B/T_2}$$

$$\frac{R_1}{R_2} = e^{(B/T_1 - B/T_2)}$$

$$\ln \frac{R_1}{R_2} = B/T_1 - B/T_2 = B \frac{(T_2 - T_1)}{T_1 T_2}$$

$$B = \frac{T_1 T_2}{(T_2 - T_1)} \ln \frac{R_1}{R_2}$$

Now, by knowing B, the value of constant A can be determined by the equation

$$R = A e^{B/T}$$

The body of the temperature probe consists of a stainless steel tube of 15 mm diameter. The thermistor is mounted inside the tube on a PVC disc and is further insulated from the tube by araldite. A waterproof coaxial cable (with electrostatic shield) of 100 m length is connected with the thermistor. The resistance of the thermistor is read by a digital meter.

The thermistor was calibrated at various temperatures ranging from 2.5°C to 53°C as shown in Table 8. The set of values of constants A and B, thus obtained by using equations (2) and (1) respectively, is shown in Table 9 and 10.

Table VIII
Calibration of Thermistor at Various Temperatures

S. NO.	Resistance, KΩ	Temperature	
		°K	°C
1.	5.35	275.5	2.5
2.	3.10	287.0	14.0
3.	2.96	288.0	15.0
4.	2.39	295.0	22.0
5.	1.42	309.0	36.0
6.	1.33	311.0	38.0
7.	0.796	326.0	53.0

Table IX
Characteristics of Thermistor of Temperature Probe

T ₁ °K	R ₁ KΩ	T ₂ °K	R ₂ KΩ	B	Average B
275.5	5.35	295.0	2.39	3.358443	
275.5	5.35	326.0	0.796	3.388444	
275.5	5.35	288.0	2.96	3.757143	
275.5	5.35	309.0	1.42	3.370720	3.372535
288.0	2.96	326.0	0.796	3.244930	
288.0	2.96	309.0	1.42	3.112738	
288.0	2.96	295.0	2.39	3.598085	

Table X
Characteristics of Thermistor of Temperatures Probe

R (KΩ)	T (°K)	A x 10 ⁻⁵	Average A
0.796	326.0	2.558	
2.96	288.0	2.430	2.5224 x 10 ⁻⁵
1.42	309.0	2.583	

A conversion for direct reading of temperature from measured resistance was derived from the following expression, and the conversion table is shown in Table 11.

$$R = A e^{B/T}$$

$$\ln R = \ln A + B/T$$

$$\frac{1}{B} (\ln R - \ln A) = \frac{1}{T}$$

or

$$T \text{ } ^\circ\text{K} = \frac{B}{(\ln R - \ln A)}$$

Substituting the values of constants A and B as determined before, we get;

$$T \text{ } ^\circ\text{C} = \frac{3,37254}{(\ln R + 10.59)} - 273$$

The error involved in measuring normal air temperature is of the order of 2°C. The resistance of the thermistor is read after about one minute i.e. after it is in equilibrium with the temperature of the surrounding fluid. For the thermistor used in the probe, an operating voltage of less than 500 mV is provided.

Table XI
Resistance-Temperature Conversion Table for the Temperature Probe

R (K Ω)	T ($^{\circ}$ C)	R (K Ω)	T ($^{\circ}$ C)	R (K Ω)	T ($^{\circ}$ C)	R (K Ω)	T ($^{\circ}$ C)
0.8644	50.0	1.2710	38.5	1.9247	27.0	3.0129	15.5
0.8785	49.5	1.2933	38.0	1.9612	26.5	3.0747	15.0
0.8929	49.0	1.1318	37.5	1.9985	26.0	3.1379	14.5
0.9076	48.5	1.3393	37.0	2.0366	25.5	3.2027	14.0
0.9225	48.0	1.3631	36.5	2.0756	25.0	3.2691	13.5
0.9378	47.5	1.3873	36.0	2.1154	24.5	3.3371	13.0
0.9533	47.0	1.4121	35.5	2.1562	24.0	3.4067	12.5
0.9692	46.5	1.4373	35.0	2.1979	23.5	3.4780	12.0
0.9853	46.0	1.4632	34.5	2.2405	23.0	3.5511	11.5
1.0018	45.5	1.4895	34.0	2.2841	22.5	3.6260	11.0
1.0186	45.0	1.5165	33.5	2.3287	22.0	3.7028	10.5
1.0358	44.5	1.5440	33.0	2.3744	21.5	3.7814	10.0
1.0533	44.0	1.5721	32.5	2.4211	21.0	3.8620	9.5
1.0711	43.5	1.6008	32.0	2.4689	20.5	3.9446	9.0
1.0894	43.0	1.6301	31.5	2.5178	20.0	4.0293	8.5
1.1079	42.5	1.6601	31.0	2.5678	19.5	4.1161	8.0
1.1269	42.0	1.6907	30.5	2.6190	19.0	4.2051	7.5
1.1462	41.5	1.7220	30.0	2.6714	18.5	4.2964	7.0
1.1660	41.0	1.7540	29.5	2.7250	18.0	4.3900	6.5
1.1861	40.5	1.7867	29.0	2.7799	17.5	4.4859	6.0
1.2067	40.0	1.8200	28.5	2.8361	17.0	4.5844	5.5
1.2277	39.5	1.8542	28.0	2.8937	16.5	4.6853	5.0
1.2491	39.0	1.8891	27.5	2.9526			

4 – CONCLUSIONS

The conductivity probe and temperature probe described in this report can be used for "in-situ" measurements required for variety of hydrological investigations dealing with water quality, water pollution, interconnections and geothermal explorations.

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RESUMO

Desenvolveram-se uma sonda de condutividade e outra de temperatura para medições in-situ, nos vários estudos hidrológicos de campo.

A sonda de condutividade tem eletrodos de platina e é alimentada por duas baterias de 12 Volts. O elemento sensor da sonda de temperatura consiste em um resistor de alto coeficiente de temperatura (NTC).

A resposta da sonda de condutividade é medida com um miliamperímetro, enquanto a resistência do termistor é indicada por um meter digital. Os valores de condutividade a temperatura são deduzidos da calibração respectiva.

As sondas são protótipos e seu intervalo de medição pode ser melhorado, dependendo dos requerimentos do problema de campo.

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