The Stevens pF Sensor
Soil Matric Potential Probe

Stevens Part #51133

Operational Manual

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Safety and Equipment Protection

WARNING!

ELECTRICAL POWER CAN RESULT IN DEATH, PERSONAL INJURY OR CAN CAUSE DAMAGE TO EQUIPMENT. If the instrument is driven by an external power source, disconnect the instrument from that power source before attempting any repairs.

WARNING!

BATTERIES ARE DANGEROUS. IF HANDLED IMPROPERLY, THEY CAN RESULT IN DEATH, PERSONAL INJURY OR CAN CAUSE DAMAGE TO EQUIPMENT. Batteries can be hazardous when misused, mishandled, or disposed of improperly. Batteries contain potential energy, even when partially discharged.

WARNING!

ELECTRICAL SHOCK CAN RESULT IN DEATH OR PERSONAL INJURY. Use extreme caution when handling cables, connectors, or terminals; they may yield hazardous currents if inadvertently brought into contact with conductive materials, including water and the human body.

CAUTION!

Be aware of protective measures against environmentally caused electric current surges. Read the Stevens Engineering Applications Note, *Surge Protection of Electronic Circuits*, part number 42147. In addition to the previous warnings and cautions, the following safety activities should be carefully observed.

Children and Adolescents.
NEVER give batteries to young people who may not be aware of the hazards associated with batteries and their improper use or disposal.

Jewelry, Watches, Metal Tags
To avoid severe burns, NEVER wear rings, necklaces, metal watch bands, bracelets, or metal identification tags near exposed battery terminals.

Heat, Fire
NEVER dispose of batteries in fire or locate them in excessively heated spaces. Observe the temperature limit listed in the instrument specifications.

Charging
NEVER charge "dry" cells or lithium batteries that are not designed to be charged.
NEVER charge rechargeable batteries at currents higher than recommended ratings.
NEVER recharge a frozen battery. Thaw it completely at room temperature before connecting charger.

Safety and Equipment Protection (Continued)

Unvented Container
NEVER store or charge batteries in a gas-tight container. Doing so may lead to pressure buildup and explosive concentrations of hydrogen.

Short Circuits
NEVER short circuit batteries. High current flow may cause internal battery heating and/or explosion.

Damaged Batteries
Personal injury may result from contact with hazardous materials from a damaged or open battery. NEVER attempt to open a battery enclosure. Wear appropriate protective clothing, and handle damaged batteries carefully.

Disposal
ALWAYS dispose of batteries in a responsible manner. Observe all applicable federal, state, and local regulations for disposal of the specific type of battery involved.

NOTICE
Stevens makes no claims as to the immunity of its equipment against lightning strikes, either direct or nearby.

The following statement is required by the Federal Communications Commission:

WARNING
This equipment generates, uses, and can radiate radio frequency energy and, if not installed in accordance with the instructions manual, may cause interference to radio communications. It has been tested and found to comply with the limits for a Class A computing device pursuant to Subpart J of Part 15 of FCC Rules, which are designed to provide reasonable protection against such interference when operated in a commercial environment. Operation of this equipment in a residential area is likely to cause interference in which case the user at his own expense will be required to take whatever measures may be required to correct the interference.

USER INFORMATION
Stevens makes no warranty as to the information furnished in these instructions and the reader assumes all risk in the use thereof. No liability is assumed for damages resulting from the use of these instructions. We reserve the right to make changes to products and/or publications without prior notice.

1 Table of Contents

2 Introduction

The Stevens pF Sensor measures a special aspect of soil moisture, the soil matric potential (ψ_m). The matric potential (also known as pressure head, tension, or water potential) is an expression for the binding forces of water to the soil matrix. The soil matric potential represents the energy acting on the soil water keeping it against the force of gravity inside the soil matrix. Water in soil will fill very small pore spaces in between the solid particles. Due to the small size of the pore space and the physical properties of water, the water will adhere (stick) to the surface of the soil particle. The adsorption of water onto the soil particle surface has a tension called capillary forces. The matric potential is the highest at low water contents and decreases with increasing water content. The relation between matric potential and water content is shown in Fig. 1 for three different soil textures:

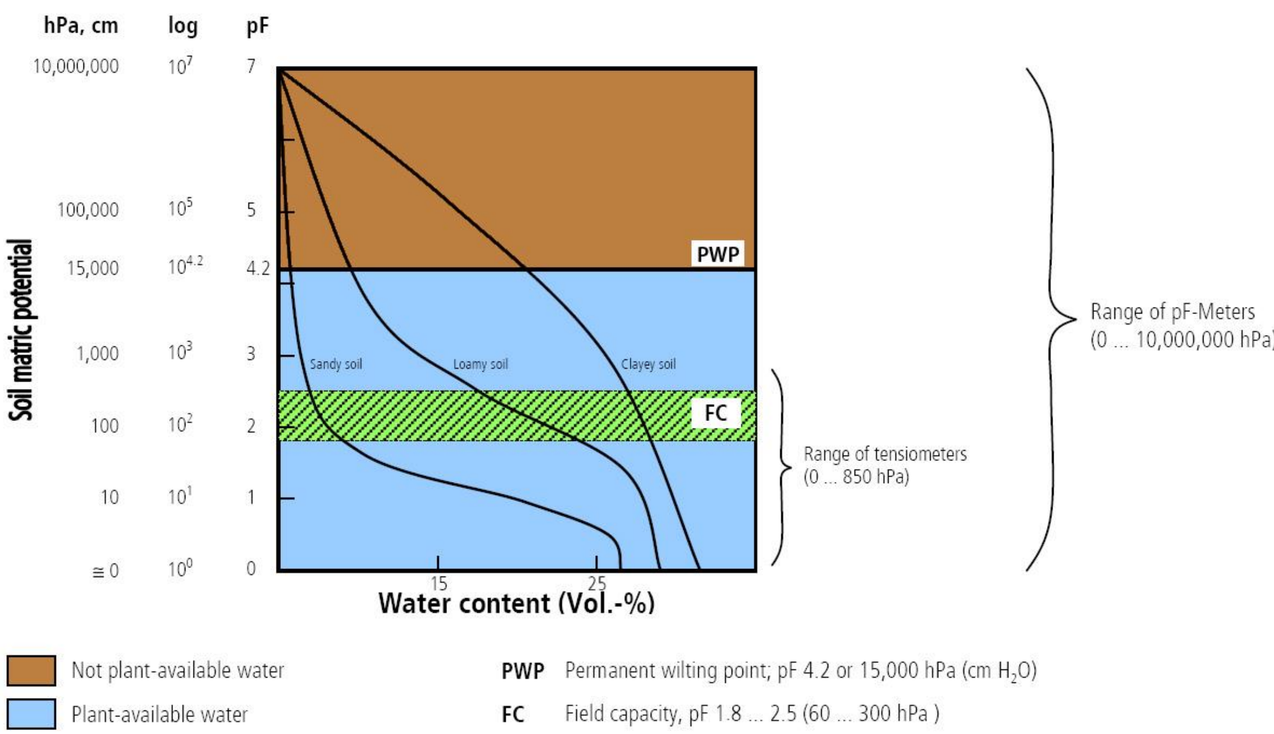

Fig. 1: Relation between matric potential and water content of different soils (Scheffer & Schachtschabel, Lehrbuch der Bodenkunde)

The matric potential is often measured in hPa or cm of water column (cm H_2O). Because of the extremely wide measuring range of pF-Meters (0 up to 10,000,000 cm H_2O) the readings are logarithm and then (analogous to the pH value) expressed as pF value. Plants are able to extract water out of the soil up to a pF value of 4.2 (15,000 cm H_2O, Fig. 1), but as the soil gets drier, plants have to establish an identical suction to overcome capillarity binding forces holding the water in the soil. Hence, in studies of plant physiology the matric potential is rather used as a benchmark for the soil moisture because it can indicate the amount of water that is available to the plant.

Convert From ↓	Convert to →	hPa	MPa	kPa	cPa	Bar	cBar
hPa	Multiply by	1	0.0001	0.1	10000	0.001	0.1
Mpa	Multiply by	10000	1	1000	1.00E+08	10	1000
kPa	Multiply by	10	0.001	1	1.00E+05	0.01	1
cPa	Multiply by	0.0001	1.00E-08	1.00E-05	1	1.00E-07	0.00001
Bar	Multiply by	1000	0.1	100	1.00E+07	1	100
cBar	Multiply by	10	0.001	1	100000	0.01	1

Table 1. Unit conversions. pF = log(-hPa)

As presented in Fig. 1, the measuring range of a tensiometer, which is often used for matric potential measurements, is limited to approx. 850 hPa. That is because a tensiometer needs water as a transmitting medium. Since water begins to boil at matric potentials of about 850 hPa even at low temperatures, it vaporizes completely at higher matric potentials than 850 hPa. For this reason, soil tensiometers are limited in that they will only provide measurements in wet soil and will not provide data in drier soils. For drier soil with matric potentials above 850 hPa, the Stevens pF-Sensor is able to provide accurate matric potential measurements by employing a new patented heat capacitance measuring principle.

Figure 2, Stevens pF Sensor.

Note that often in the soil science literature, matric potential is expressed as a negative number and water head is expressed as a positive number. Because the logarithm of a negative number has no meaning, we will express matric potential as a pF value or a positive number in this manual.

3 Soil Considerations

Knowing when to irrigate crops and how much water to use has been an important question since ancient times. Soil moisture values are particularly important for irrigation optimization and to the health of a crop.

The following are terms commonly used in soil hydrology:

Soil Saturation: refers to the situation where all the soil pores are filled with water. This occurs below the water table and in the unsaturated zone above the water table after a heavy rain or irrigation event. After the rain event, the soil moisture (above the water table) will decrease from saturation to field capacity. If the soil is completely saturated, water will drain downward, or possibly pond on the surface.

Field Capacity: refers to the amount of water left behind in soil after gravity drains saturated soil. Field capacity is an important hydrological parameter for soil because it can help determine the flow direction. Soil moisture values above field capacity will drain downward recharging the aquifer/water table. Also, if the soil moisture content is over field capacity, surface runoff and erosion can occur. If the soil moisture is below field capacity, the water will stay suspended in between the soil particles from capillary forces. The water will basically move only upward at this point from evaporation or evapotranspiration. At field capacity, the pF will be about 2 depending on the soil.

Permanent Wilting Point (PWP): refers to the amount of water in soil that is unavailable to the plant. Below PWP the soil is so dry that the water in the soil is tightly held to the solid particle to a point in which plants are unable to extract it. Below PWP the pF will have higher values starting at 4.2.

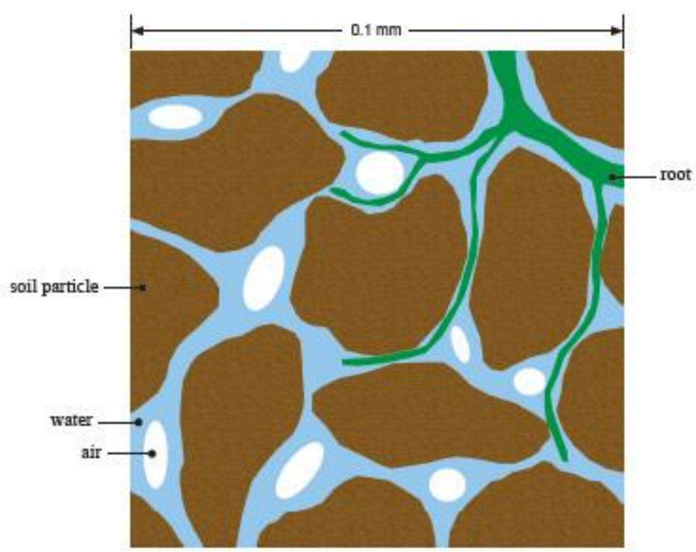

Figure 3. Unsaturated soil is composed of solid particles, organic material and pores. The pore space will contain air and water.

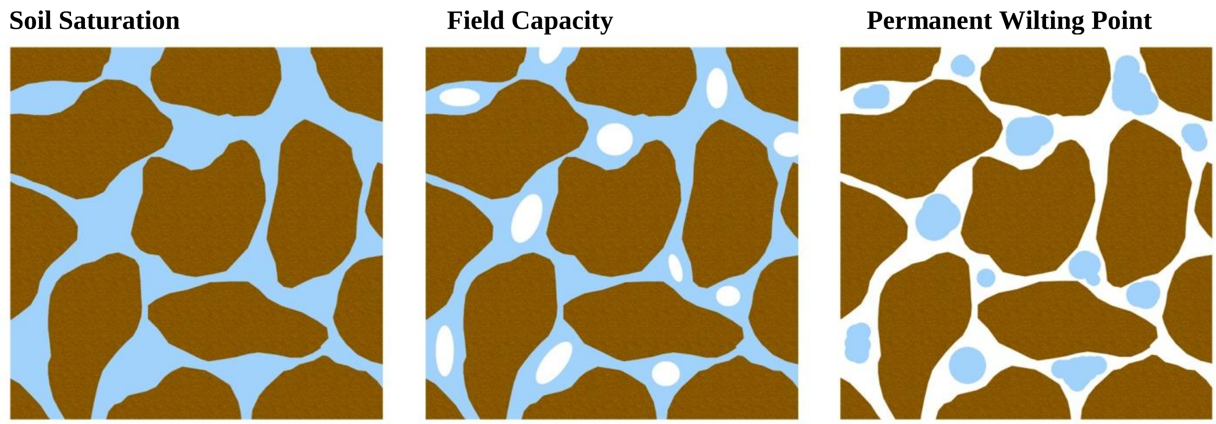

Figure 4. Hydrological conditions of soil. Field capacity, saturation and PWP.

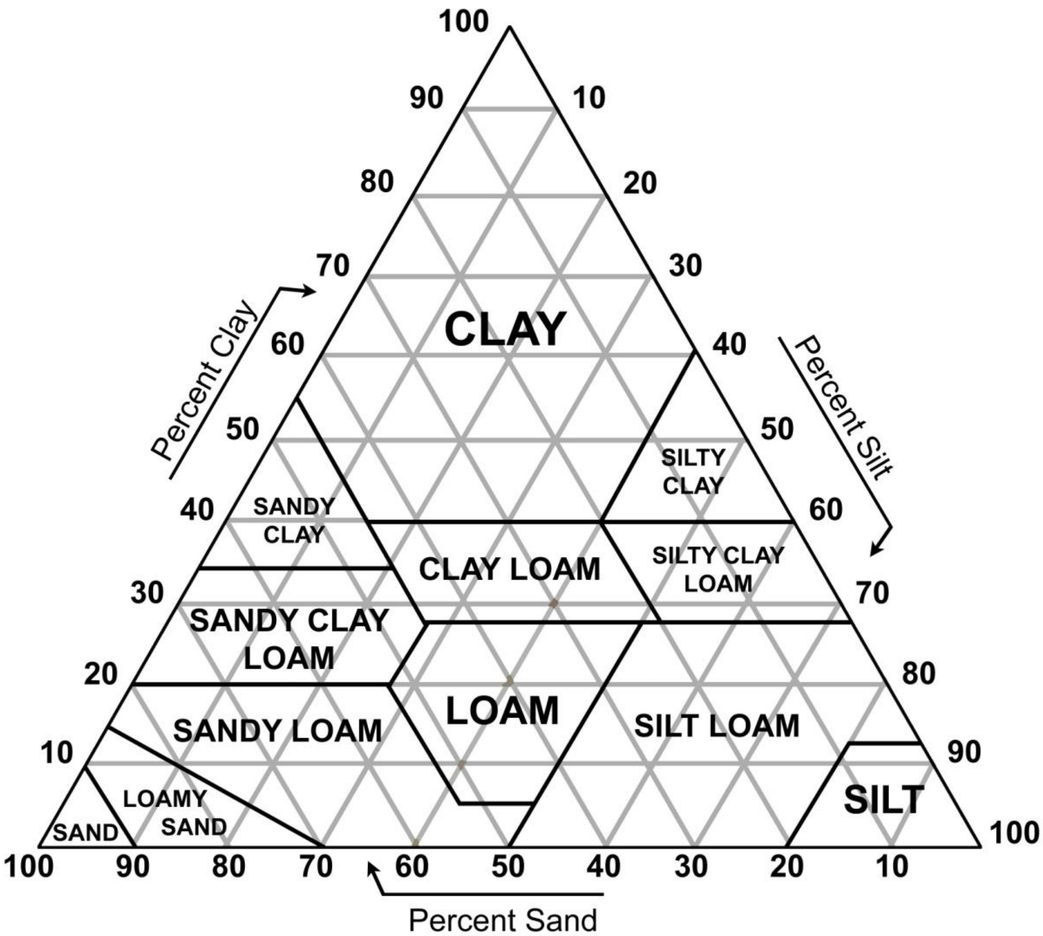

Figure 5. Soil Textural Triangle showing textural classes of soil.

Mineral soil is composed of sand, silt, and clay and the composition(texture) can have major influences on soil hydrology. For example, clay has smaller particle sizes than sands and silts and will have stronger capillary forces resulting in higher pF values. Figure 5 describes soil textural classes based on composition.

4 Measurement Principle

Sensor Construction

The sensor consists of an equilibrium body made of porous ceramic material, in which the actual matric potential of the surrounding soil is established. The equilibrium body is potted into an 80 mm long stainless steel housing, which includes the electronics. At the top of the stainless steel housing there is a bushing, which acts as strain relief for the cable.

Measuring Principle

The moisture level of the porous ceramic sensor tip will equilibrate with the moisture of the soil so that changes in soil moisture will reflect the chances of the moisture of the ceramic tip. Inside of the ceramic tip is a heating element that will deliver a pulse of heat to the ceramic tip. The heat capacity of the surrounding soil is calculated from the heating and cooling characteristics of the equilibrated ceramic tip. The soil's matric potential can then be calculated from the soil's heat capacity. That is to say that the higher water content the more energy it takes

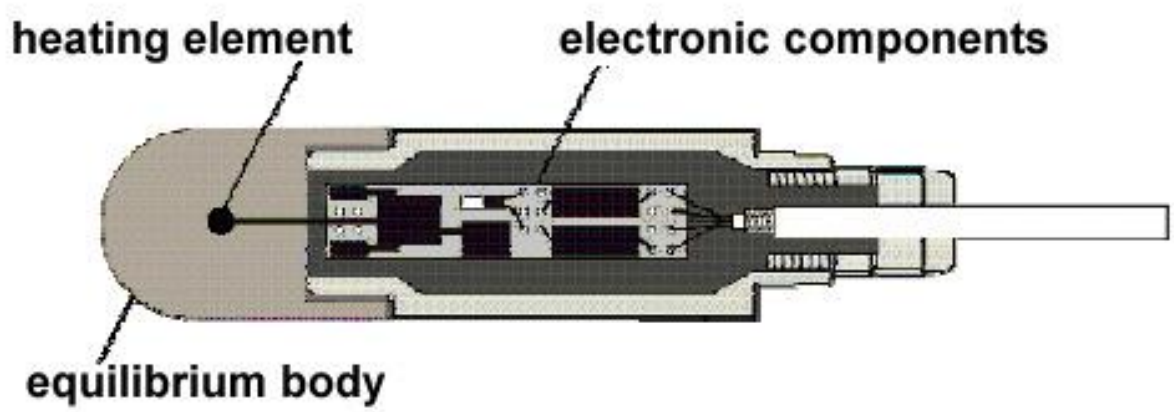

Figure 6, Diagram of the pF Sensor.

to heat it up. The heat energy is related to the energy it takes to pull water out of the soil therefore, accurate matric potential measurements can be easily calculated from accurate heat capacity measurements.

Factory Pre-Calibration

The pF Sensor undergoes a rigorous calibration process in order to accurately capture the range of matric potentials observed in soil, particularly dry soils. Within the calibration process of the pF Sensor, the heat capacity is measured exactly at different given water potentials. A list of raw values is created which is characteristic for any sensor and which is stored in the sensor's electronics. To cover the broad range of potentials from pF 0 up to pF 7, different methods were used to produce different pressures.

While small matric potentials can be simulated by hanging the sensor in a water column and pressure chambers, these methods will not accommodate matric potentials above pF 4.2. To calibrate above pF 4.2, the pF Sensor can be calibrated at different defined air humidity values. For example, a soil sample in equilibrium with air at 90 % relative humidity corresponds with a pF value of 5. A pF value of 7 is a theoretical reading, because it can only be generated under completely dry conditions in the drying oven at 105 °C. Therefore the sensors are calibrated up to a pF value of about pF 6.5 and the range up to pF 7 is covered by extrapolation. Because the matric potential is determined by thermal means, the measurement will not be influenced by soil salinity.

5 Installation

1) Be careful with the ceramic tip of the pF sensor, it is fragile.
2) Before installation into soil, moisten the ceramic tip by soaking it in water for about one minute.
3) Once the ceramic tip has been moistened, always keep the tip facing downward. If the sensor is held upside down, water may get into the aeration vent tube.
4) To install into the soil, prepare a pit. Prepare a place or slot in the side wall the same size and shape of the sensor with a knife or trowel.
5) Carefully place the sensor in the precut slot diagonally or vertically with the ceramic tip pointing down. Do not apply pressure to the ceramic tip to install it.
6) Wire the senor to the data logger and perform a communication test.
7) The cable can be looped downward so that the cable does not conduct water to the sensor tip. The cable may also be place in electrical conduit to protect the cable in the ground.
8) Carefully back fill the hole, packing soil around the exposed side the sensor in the slot.
9) For deep installations or difficult soils, the user can prepare a pit and pack the disturbed soil aggregate from the pit around the sensor body.
10) The sensor needs to be at a depth greater than 3.9 in (10 cm). Temperature fluctuations near the surface may affect readings.

SDI-12 Communication
SDI-12 stands for Serial Data Interface at 1200 Baud. It is a digital standard communication protocol for environmental multi sensors such as weather stations, water quality sondes and soil sensors. SDI-12 is a serial addressable bus the can have multiple sensors with different addresses on the same bus. A common communication protocol is used to program the sensors and query the sensor for measurements. For more information about SDI-12 please visit www.sdi-12.org

SDI-12 Command
aI! sensor transmits identification and serial number
aM! measure pF value and temperature; Returns: 0092 (2 values within 9 seconds)
aM1! measure temperature; Returns: 0031 (1 value within 3 seconds)
aM2! measure pF value; Returns: 0081 (1 value within 8 seconds)\
aM3! measure supply voltage; Returns: 0021 (1 value within 2 seconds)
aD0! display readings
aAb! change SDI-12 address from a to b

Wiring, SDI-12

Pink Wire	SDI-12 Data
Brown	12 VDC Power Supply
Grey	Common Ground

Precautions/Considerations

1) Do not hold sensor ceramic end up while moist because water will get into the aeration tube.
2) Moisten the ceramic tip in water for about one minute before installation.
3) Install with ceramic tip downward (or diagonal facing downward)
4) Duty Cycle is one measurement every 15 minutes.
5) To install, use knife to cut out a slot in the side wall of the pit.
6) Install the sensor tip at least 10 cm underground to prevent temperature effects.
7) Do not obstruct the aeration tube.
8) Desiccant Cartridge, Stevens P/N 93030-001 is recommended to be attached to the end to the vent tube, to prevent moisture from accumulating.
9) Do not shake the sensor.

Technical Specifications

- Warm up time: 20 to 30 seconds
- Measurement range of pF: 7 to 0 pF
- Measurement range of temperature: -40 to +176 F (-40 to +80 C)
- Power: 7 to 13 volts DC
- Current Draw: 55 mA while active (about 5 seconds), 2 mA while idle.
- Dimensions: 3.93 in Length x 0.78 in Diameter (100 mm x 20 mm)
- Resolution of pF: 0.01 pF
- Resolution of Temperature: 0.1 C
- Body Type: Stainless Steel body material, fully-potted internal electronics.
- Sensor Head: Ceramic
- Output Signal: SDI-12
- Cable Length: 32.8 ft (10 m) standard or up to 262.4 ft (80 m) optional.