

Clogged Gutter Detector

ECE 445 Senior Design Laboratory

Design Document — Fall 2026

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1. Introduction

1.1 Problem and Solution

Residential gutters and downspouts direct rainwater away from roofs and building foundations. Inadequate drainage can saturate soil near the foundation and increase the risk of moisture entering the building [1]. A clogged gutter or downspout can therefore become a maintenance problem before a homeowner notices visible overflow.

Inspecting elevated gutters also introduces a fall hazard. The U.S. Consumer Product Safety Commission reports injuries associated with ladders and stools in its National Electronic Injury Surveillance System data [2]. Although these injuries are not limited to gutter maintenance, they demonstrate the broader safety concern associated with elevated inspections.

The proposed **Clogged Gutter Detector** is an outdoor monitoring node installed beside the downspout of a monitored gutter zone. Instead of identifying leaves or measuring debris height, the system compares two conditions: whether the precipitation sensor indicates rain and whether water reaches a sensing location inside the downspout.

A precipitation sensor detects surface wetting associated with rainfall. A conductivity-based water-presence probe uses two stainless-steel electrodes to detect water at the monitored downspout location. If the rain indication persists but corresponding water presence is not detected after a defined runoff delay and observation interval, the system reports a **possible gutter obstruction**.

An ESP32-WROOM-32E processes the sensor measurements and transmits an alert over a 2.4-GHz Wi-Fi network to an external test server or dashboard. During idle operation, the main processor remains in deep sleep while the ultra-low-power coprocessor monitors the precipitation input. A protected rechargeable 18650 lithium-ion battery powers the electronics, and a solar panel provides supplemental charging [5], [26], [27].

This approach improves on the original ultrasonic-debris concept because it does not require the system to determine the height, shape, or composition of material inside the gutter. Instead, it detects an abnormal drainage condition: the precipitation sensor indicates rain, but water is not detected at the monitored downspout location.

The system will report a **possible obstruction**, rather than guarantee that a clog exists. Light rain, delayed runoff, residual moisture, sensor placement, and other drainage conditions can affect the relationship between the two measurements. Similarly, water detected at the electrodes does not prove that the entire gutter is clear.

Design Revision Based on Proposal Feedback

The instructor requested reconsideration of the original flow sensor because the project requires a correlation between rainfall and downspout water presence rather than an accurate measurement of volumetric flow.

The revised design therefore replaces the SEN0217 Hall-effect flow sensor with a **two-electrode conductivity-based water-presence probe**. The original sensor uses a rotating element and Hall-effect sensing to measure flow [7]. Its inline installation introduces unnecessary mechanical complexity and restricts the prototype water path.

The revised probe has no moving parts and can operate from the existing 3.3-V system domain. This eliminates the dedicated TPS61240 5-V flow-sensor supply and the Hall-sensor pulse-level divider from the previous architecture [10], [25].

The electrodes will be mounted on an insulating support so that water, rather than the downspout wall, provides the conductive connection between them. This is especially important for metal downspouts, where directly mounting both electrodes against the metal could electrically short the sensing path.

The revision provides:

- No moving sensing components.
- Minimal obstruction of the downspout.

- Direct measurement of the required binary water-presence condition.
- Operation from the existing 3.3-V system supply.
- Removal of the dedicated 5-V flow-sensor boost circuit.
- Lower sensor and supporting-circuit cost.
- Simpler prototype mounting.

The previously submitted KiCad schematic is an earlier design iteration. The final schematic and PCB will be revised to implement the architecture described in this document.

1.2 Visual Aid

The monitoring node will be mounted beside a downspout. Its precipitation sensor will face upward at a slight angle to encourage drainage, and its solar panel will be positioned where it receives illumination. Two insulated wires will connect the enclosure to the conductivity electrodes inside the downspout.

The router, server, and user display are external infrastructure and are outside the project hardware boundary.

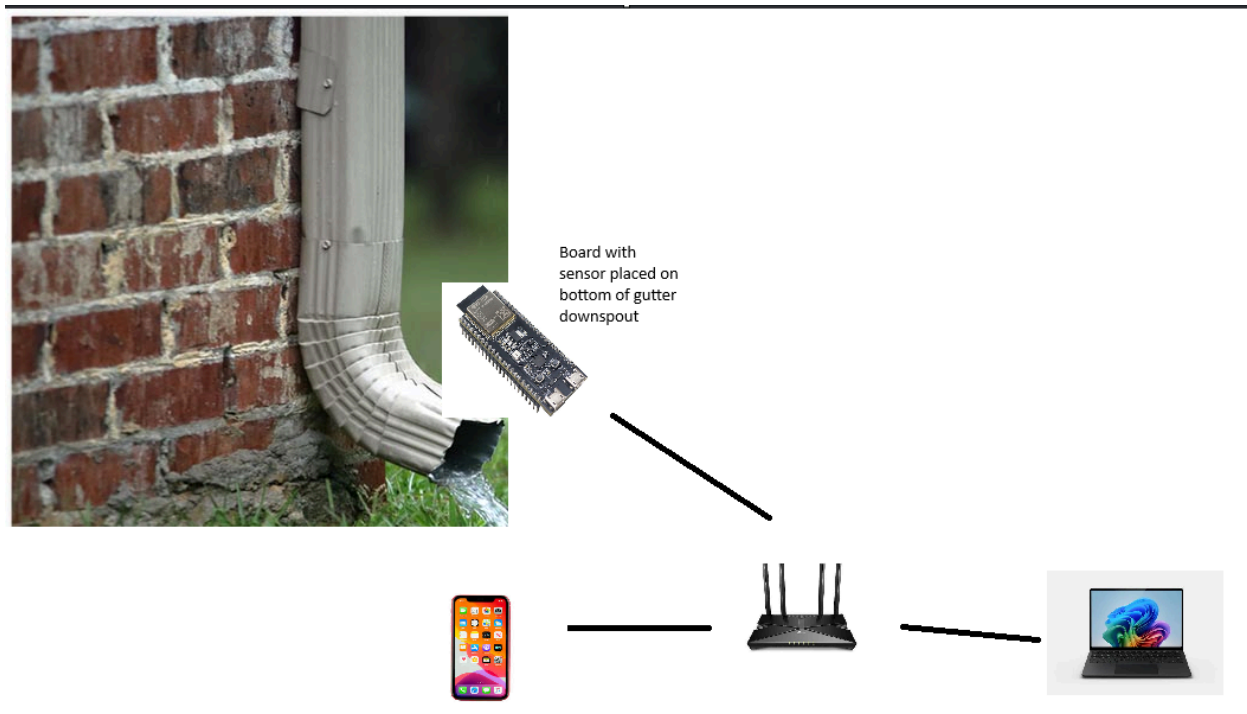


Figure 1. Intended installation and use of the Clogged Gutter Detector. The node compares precipitation indication with water presence at the monitored downspout and communicates a possible-obstruction alert through external Wi-Fi infrastructure.

1.3 High-Level Requirements

The project will be considered successful when it satisfies the following requirements:

1. **Rain detection:** In at least 9 of 10 simulated-rain trials, the system shall detect the rain condition and begin the downspout evaluation sequence within **10 seconds** of initial water contact with the precipitation sensor.
2. **Water-presence detection:** Using the calibrated prototype fixture, the conductivity probe shall correctly classify water-present and dry conditions in at least **9 of 10 trials for each condition**, using a **10-second observation interval**.
3. **Obstruction alert:** When the rain condition persists and insufficient water presence is detected after the runoff delay and observation interval, the system shall transmit a valid JSON alert accepted by the configured server and return the main processor to deep sleep within **10 seconds after confirmation**, in at least 9 of 10 trials with the test network available.
4. **Power operation:** The main system rail shall remain at **3.3 V $\pm$ 5%** during sensing and Wi-Fi transmission. With the battery below 4.1 V and under the defined bright-light test condition, the system shall provide at least **50 mA of positive battery charging current** after reaching steady state.

The runoff delay is separate from the 10-second water-observation interval. Its initial value will be **30 seconds**, with adjustment based on measured runoff arrival times in the prototype fixture. These timings are design targets, rather than completed test results.

2. Design

2.1 Block Diagram

The design contains three primary internal subsystems:

- **Sensor subsystem:** precipitation sensing and downspout water-presence sensing.
- **Microcontroller and communications subsystem:** sampling, calibration, decision logic, sleep control, and alert transmission.
- **Power subsystem:** solar input conditioning, battery charging, source selection, and regulated 3.3-V power.

A solar input-conditioning stage is included because the selected panel's actual voltage can exceed its nominal "5-V" description.

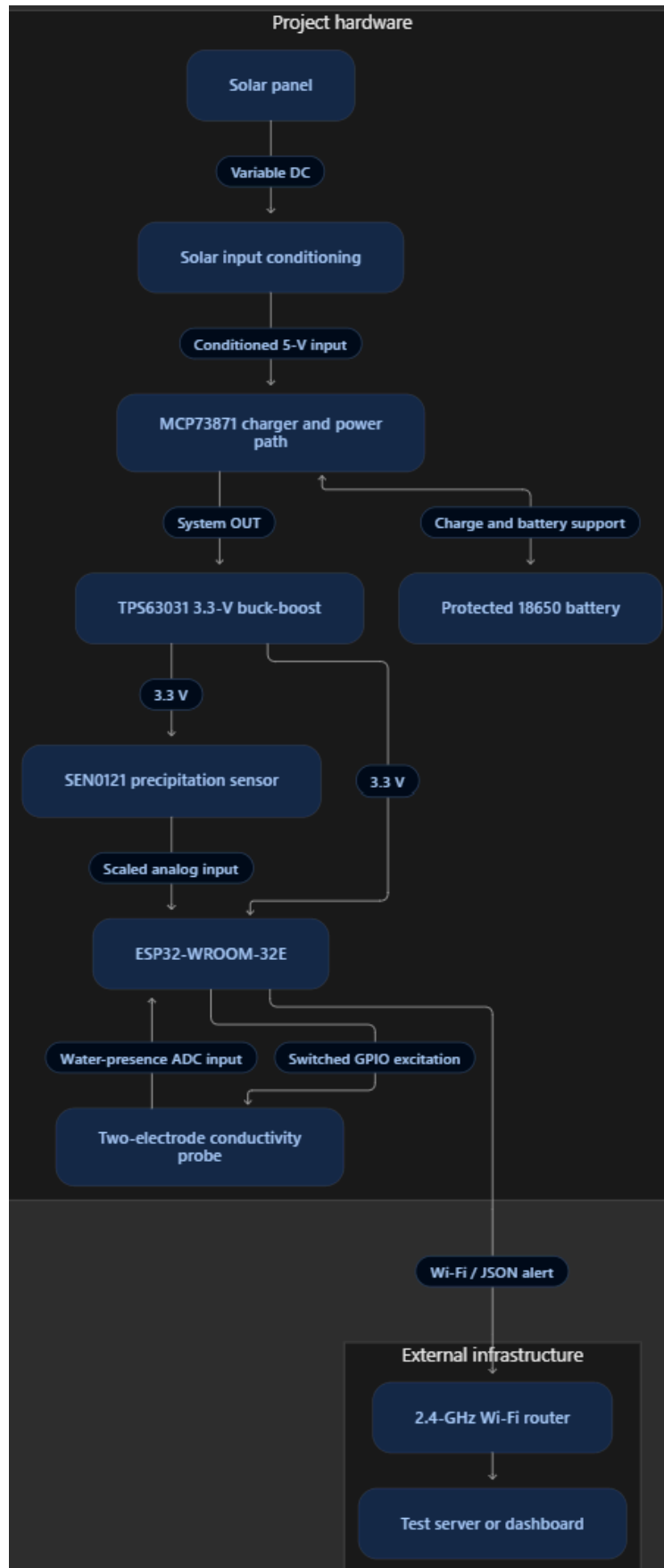


Figure 2. Revised system block diagram. The conductivity probe replaces the Hall-effect flow sensor. The external router and server are outside the project hardware boundary.

Subsystem Interfaces

Interface	Electrical or functional definition
Solar panel to input conditioning	Variable photovoltaic output; design must accommodate the panel's open-circuit voltage
Input conditioning to charger	Nominal 5.0-V output; target 4.75–5.25 V when sufficient solar input is available
Charger to battery	Single-cell lithium-ion charging using the selected 4.2-V charger variant
Charger OUT to TPS63031	System supply selected from solar input or battery by the charger power path
TPS63031 to system electronics	3.3 V $\pm$ 5%
Precipitation sensor to ESP32	Analog output scaled before connection to ADC1
ESP32 to conductivity probe	Short-duration GPIO excitation through a current-limiting resistor
Conductivity probe to ESP32	Analog voltage at an ADC1 input
ESP32 to external server	JSON alert over the configured 2.4-GHz WLAN

2.2 Physical Design

The PCB, battery, and power electronics will be contained in a weather-resistant polycarbonate enclosure approximately **120 mm × 90 mm × 45 mm**. The Hammond 1554FL2GY provides a reference enclosure of this size [28]. Its finished suitability will depend on the mounting arrangement, internal clearances, and sealing of added penetrations.

The enclosure will mount beside the downspout using a bracket or strap arrangement. The precipitation sensor will be located outside the enclosure with its sensing surface exposed and its connector protected. A slight mounting angle will help water drain from the sensing surface.

The selected solar panel measures approximately **113 mm × 66 mm × 2.6 mm** [27]. It will mount above or beside the enclosure without shielding the precipitation sensor.

The conductivity electrodes will be supported by a small insulating carrier positioned against the inside downspout wall. A starting electrode gap of approximately **5 mm** will be evaluated during calibration. The gap and orientation will be adjusted so representative runoff can contact both electrodes.

The probes must contact a likely runoff path. Water in a downspout may travel along a wall rather than fill the entire cross section; therefore, positioning the electrodes arbitrarily in the center could miss normal runoff.

The carrier will be mechanically secured, insulated from any metal downspout wall, and shaped to minimize debris retention. Cable entries will include sealing and strain relief.

Mechanical Design Parameters

Feature	Proposed specification
Electronics enclosure	Approximately 120 × 90 × 45 mm
Solar panel	Approximately 113 × 66 × 2.6 mm
Precipitation sensing board	Approximately 30 × 20 × 6 mm
Electrode material	Stainless steel
Initial electrode spacing	Approximately 5 mm; subject to calibration
Electrode support	Electrically insulating carrier
Probe position	Near an experimentally identified runoff path
Mounting	Secured bracket or straps beside the downspout
Cable routing	Sealed, strain-relieved entries with drip loops

The final mechanical drawing will show the enclosure dimensions, solar panel, precipitation sensor, insulating probe carrier, electrode spacing, mounting hardware, cable routing, and water path.

2.3 Sensor Subsystem

The sensor subsystem provides the two measurements required by the detection algorithm: precipitation indication and downspout water presence. It directly supports the first two high-level requirements.

2.3.1 Precipitation Sensor

The precipitation detector will use the **DFRobot SEN0121 analog steam and water sensor**. The manufacturer specifies operation from 3.3 V or 5 V and an approximate output range of 0–3.0 V when powered from 3.3 V [6].

The sensor detects moisture on its surface. It does not independently measure rainfall intensity or prove that rain is still falling after the surface becomes wet.

The sensor will operate from the regulated 3.3-V rail. Its output will pass through a **10-kΩ series resistor and 20-kΩ resistor to ground**, producing:

$$V_{RainADC} = V_{Sensor} \frac{20}{10+20}$$

For a 3.0-V sensor output:

$$V_{RainADC} = 2.0V$$

This scaling provides margin within the ESP32 ADC measurement range. ADC attenuation will be configured appropriately, and calibration will use the complete assembled circuit.

At least **30 dry readings and 30 wetted readings** will be collected. If the distributions are sufficiently separated, a threshold and hysteresis band will be selected between them.

The ULP coprocessor will sample the precipitation input approximately once per second using ADC1. Three consecutive readings above the wet threshold will trigger the main processor [31].

A lower release threshold will identify the transition back toward the dry state. Testing will include residual moisture and condensation to determine the limitations of this low-cost sensor.

2.3.2 Conductivity-Based Water-Presence Probe

The downspout probe will use two stainless-steel electrodes mounted on an insulating support.

The proposed sensing circuit contains:

- **100-kΩ, 1% series excitation resistor, R_S .**
- **100-kΩ, 1% ADC pull-down resistor, R_P .**
- **100-nF capacitor** from the ADC node to ground.

The electrical path is:

ESP32 GPIO $\rightarrow R_S \rightarrow$ electrode A $\rightarrow$ water path $\rightarrow$ electrode B $\rightarrow$ ADC node

The ADC node connects to ground through R_p . The capacitor filters the measured voltage.

When the electrodes are dry, the conductive path between them is approximately open and the pull-down holds the ADC node near ground. When water bridges the electrodes, the ADC voltage rises.

An approximate model is:

$$V_{ADC} = V_{GPIO} \frac{R_p}{R_s + R_w + R_p}$$

where R_w is the effective resistance of the water path.

For nominal 3.3-V excitation:

Illustrative water-path resistance	Approximate ADC voltage
Open circuit	0 V
100 k Ω	1.10 V
1 M Ω	0.275 V
10 M Ω	0.032 V

These are illustrative calculations, not assumed rainwater properties. Actual readings depend on conductivity, electrode spacing, contact area, contamination, and placement.

Even if water directly shorts the electrode gap, the nominal ADC voltage is limited to:

$$V_{ADC,max} = 3.3 \frac{100}{100+100} = 1.65V$$

The GPIO will apply excitation only during measurement. The firmware will initially wait **50 ms** for settling, collect several ADC readings, average them, and then drive the excitation low. The settling time will be verified experimentally.

Short excitation periods reduce power consumption and the duration of applied DC voltage. They do not eliminate electrode corrosion or contamination.

2.3.3 Probe Calibration

Calibration will use the actual electrode carrier and downspout fixture.

The team will record:

1. At least 30 readings with the probe dry.
2. At least 30 readings with representative runoff contacting both electrodes.
3. Readings with residual droplets after runoff stops.
4. Readings using low-conductivity water representative of rainfall.
5. Readings after limited contamination or repeated wetting.

A threshold will only be accepted if the dry and water-present readings are sufficiently separated. If they overlap, electrode geometry, mounting, filtering, or resistor values will be revised.

During the 10-second observation interval, the probe will be sampled once per second. Water detected on at least **three of the ten samples** will count as evidence that runoff reached the monitored location.

The probe measures water presence. It does not establish flow rate or distinguish flowing water from retained water that bridges the electrodes.

2.4 Microcontroller and Communications Subsystem

The system will use the **ESP32-WROOM-32E**, which integrates processing, ADC inputs, low-power functions, and 2.4-GHz Wi-Fi. The manufacturer specifies a 3.0–3.6-V operating supply [5].

Proposed Pin Assignment

Function	Proposed ESP32 pin	Purpose
Precipitation ADC	GPIO34 / ADC1_CH6	ULP precipitation monitoring
Water-presence ADC	GPIO35 / ADC1_CH7	Conductivity measurement
Probe excitation	GPIO25	Switched excitation
Battery ADC	GPIO32 / ADC1_CH4	Battery-voltage measurement
UART TX	GPIO1	Programming and debugging
UART RX	GPIO3	Programming and debugging
Enable/reset	EN	Reset control
Boot selection	GPIO0	Programming mode

These are proposed assignments for the revised schematic. ADC1 is used for the sensor measurements to avoid ADC2/Wi-Fi resource conflicts.

2.4.1 Firmware Sequence

The firmware will perform the following sequence:

1. Initialize ADC configuration, calibration values, network configuration, and retained state.
2. Disable probe excitation and enter deep sleep.
3. Sample the precipitation sensor approximately once per second using the ULP.
4. Wake after three consecutive wet readings.
5. Begin an initial **30-second runoff delay**, while checking whether the rain indication persists.
6. If the rain indication clears, end the evaluation without an obstruction alert.
7. Otherwise, sample the conductivity probe once per second for 10 seconds.
8. Classify at least three water-present samples as runoff detected.
9. If fewer than three samples indicate water and the rain indication persists, classify a possible obstruction.
10. Transmit an alert when required, disable probe excitation, and return to deep sleep.

During a continuing wet event, a proposed **five-minute timer** will allow periodic reevaluation. Retained state will prevent the wet sensor from immediately causing repeated wakeups and duplicate alerts.

The event will rearm after the precipitation input remains below its release threshold for **60**



Figure 3. Proposed firmware sequence. A runoff delay precedes water-presence evaluation, and retained event state limits repeated wakeups and duplicate alerts.

2.4.2 Alert Packet

A representative alert packet is:

None

```
{
  "device_id": "gutter-node-01",
  "rain_detected": true,
  "water_detected": false,
  "water_present_samples": 0,
  "possible_clog": true,
  "battery_voltage": 3.87
}
```

The battery value shown is an example.

Battery voltage will be measured through a **100-k Ω /100-k Ω divider** with a capacitor at the ADC node. A 4.2-V battery produces approximately 2.1 V at the ADC input. The complete measurement will be calibrated against a DMM.

The server will acknowledge receipt with a successful application response. If transmission fails, the firmware will retain a pending alert and return to sleep after a bounded attempt. A communications failure will not be presented as successful delivery.

The prototype will demonstrate receipt at a test endpoint. A complete production mobile application is outside the core project scope.

2.5 Power Subsystem

The system uses a protected lithium-ion cell with solar-assisted charging. The revised sensor subsystem requires only a 3.3-V operating domain.

2.5.1 Solar Panel and Input Conditioning

The selected reference panel is the **Voltaic P124 / Adafruit 5368**, advertised as a 5-V, 1.2-W panel. Its published specifications include a **7.09-V open-circuit voltage**, approximately **6.07-V peak-power voltage**, and **200-mA peak current** [27].

Therefore, the panel must not be treated as a regulated 5-V source.

The voltage will be regulated using a **reverse bias zener diode** with breakdown voltage of about 6V. This will keep the input voltage to the MCP73871 within its recommended operating range.

A large output capacitor will also be added at the output of the solar panel to quickly supply power during a load step.

2.5.2 Battery and Charge Management

The battery will be a **Tenergy 30016 protected 18650 cell**, rated at **3.7 V nominal and 2600 mAh** [26].

Its nominal stored energy is:

$$E = 3.7 \times 2.6 = 9.62Wh$$

Actual usable energy will be lower because of conversion losses, discharge limits, temperature, and aging.

Charging will use the **MCP73871-2CAI/ML**, with its 4.2-V charging option and system-load sharing [8], [23]. The system regulator will connect to the charger's **OUT** node, rather than treating the battery as the only system-power source.

The target charge-current programming resistor is:

$$R_{PROG1} = 5.1k\Omega$$

Using the programming relationship:

$$I_{REG}(mA) = \frac{1000}{R_{PROG1}(k\Omega)}$$

gives:

$$I_{REG} \approx 196mA$$

This is a programmed target, not a guaranteed solar charging current. Available panel power and simultaneous system load can reduce charging.

The final schematic and populated board will be checked to confirm the selected charger variant, programming resistor, termination configuration, and control-pin connections.

The THERM circuit will monitor battery temperature. Its resistor network will be selected using the thermistor's resistance curve and the permitted battery charging range; selecting an arbitrary 10-k Ω thermistor alone does not establish suitable temperature limits.

2.5.3 Regulated 3.3-V Supply

The main rail will use the **TPS63031 fixed 3.3-V buck-boost converter** [9].

A buck-boost converter is appropriate because the battery voltage can move above and below 3.3 V during discharge. The regulator must also accommodate the charger's system OUT voltage when solar power is available.

The required operating range is:

$$3.135V \leq V_{System} \leq 3.465V$$

The rail will power the ESP32, precipitation sensor, and conductivity circuit.

The layout will include short switching-current paths, suitable decoupling, an appropriately rated inductor, and local capacitance near the ESP32. The completed board will be tested under a **500-mA transient load** and actual Wi-Fi operation.

The previous TPS61240 flow-sensor boost converter is removed. The new solar input-conditioning stage serves a different purpose: protecting and conditioning the charger input.

2.5.4 Energy Budget

Deep sleep reduces processor consumption, but total idle consumption also includes the precipitation sensor, charger, regulator, divider networks, and any indicators.

Battery runtime will be estimated from measured average current:

$$t_{Battery} \approx \frac{C_{Usable}}{I_{Average}}$$

Solar-assisted energy balance will be evaluated by comparing measured daily energy consumption with realistic daily charging energy.

The design will not claim indefinite autonomous operation based only on battery capacity or the panel's peak rating.

2.6 Requirements and Verification

Subsystem	Requirement	Verification
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Precipitation sensing	Wake and begin evaluation within 10 s in at least 9 of 10 simulated-rain trials; no rain-triggered wake during a 5-minute dry test	Record a dry baseline, apply repeatable spray, and measure first water contact to wake. Repeat 10 trials, then perform the dry test.
Water-presence sensing	Correctly classify at least 9 of 10 water-present trials and 9 of 10 dry trials using the 10-s observation interval	Mount the final probe in the fixture. Direct representative runoff across both electrodes, record ADC values and wet-sample counts, and repeat with a dry probe.
Electrode insulation	No low-resistance dry connection through the carrier or downspout wall	With electronics disconnected, measure resistance between electrodes and between each electrode and a metal test wall. Inspect mounting insulation.
System logic	Correctly classify at least 9 of 10 rain-with-water trials and 9 of 10 rain-without-water trials	Perform paired trials using the selected runoff delay and observation interval. Record classification and timing.
Rain release	Stop or cancel obstruction evaluation when the rain indication clears	Remove the simulated-rain condition, allow the sensor to drain, and confirm the release logic. Repeat 10 times.
Communications	Successful JSON receipt and return to sleep within 10 s after confirmation in at least 9 of 10 trials with the network available	Monitor server logs, serial timestamps, and a sleep marker during possible-obstruction trials.
Communications failure	Retain a pending alert and return to sleep within the bounded attempt period	Disable the router or endpoint and verify failure logging, retained state, and sleep entry.
3.3-V rail	Maintain 3.135–3.465 V during sensing and a 500-mA transient test	Sweep representative system-input voltages and apply load steps while measuring with a DMM and oscilloscope. Repeat during actual Wi-Fi transmission.
Solar input conditioning	Produce 4.75–5.25 V at the charger input when adequate input power is available	Use a current-limited source to represent panel voltage, then test with the actual panel. Check startup, shading, and unloaded conditions.

Battery charging	Supply at least 50 mA positive battery current with battery below 4.1 V under the defined bright-light condition	Measure battery current after steady state. Record illumination method, panel orientation, input voltage, battery voltage, and system load.
Charge regulation	Regulate near the selected 4.2-V setpoint without exceeding the cell's permitted charging limit	Perform supervised charging with a calibrated DMM and current measurement. Confirm current taper near full charge.
Temperature protection	Suspend charging outside the configured permitted battery-temperature range	Substitute resistances representing cold and hot thermistor conditions; confirm charging suspension and recovery.
Repeated-event operation	Avoid immediate repeated wakeups and duplicate alerts while the precipitation sensor remains wet	Hold the sensor wet for at least 10 minutes and record wakeups, evaluation intervals, and alert count.
Enclosure assembly	Keep the PCB and battery dry during a controlled splash test	Conduct a ground-level test with the completed enclosure. Disconnect power before opening and inspecting for ingress.

The test fixture, water type, sensor orientation, supply conditions, and network conditions will be recorded so results can be reproduced [4].

2.7 Tolerance Analysis

2.7.1 Conductivity Interface

The revised conductivity interface replaces the obsolete Hall-sensor divider analysis.

The proposed resistors are:

$$R_s = 100k \pm 1\% \text{ and } R_p = 100k \pm 1\%$$

The highest ADC voltage occurs when the water-path resistance approaches zero, excitation is at the maximum permitted rail voltage, R_p is maximum, and R_s is minimum:

$$V_{ADC,max} = 3.465 \frac{101}{99+101}$$

$$V_{ADC,max} \approx 1.750V$$

Thus, the proposed circuit limits the ADC voltage to approximately 1.75 V under this worst-case combination.

Maximum current with a shorted water path occurs with both resistors at their minimum:

$$I_{max} = \frac{3.465}{99000+99000}$$

$$I_{max} \approx 17.5 \mu A$$

For an illustrative water-path resistance of 100 kΩ, the minimum measured voltage is:

$$V_{wet,min} = 3.135 \frac{99}{101+100+99}$$

$$V_{wet,min} \approx 1.035V$$

The corresponding maximum is:

$$V_{wet,max} = 3.465 \frac{101}{99+100+101}$$

$$V_{wet,max} \approx 1.167V$$

These calculations show the effect of supply and resistor tolerances. They do not prove that real rainwater will produce a 100-kΩ path.

The most significant uncertainty is water conductivity and electrode contact. Successful implementation therefore requires experimentally separated dry and wet distributions. A threshold cannot be justified solely from nominal resistor values.

2.7.2 Supply Transient Margin

The 3.3-V requirement permits a maximum downward deviation of:

$$\Delta V_{Allowed} = 3.3 - 3.135 = 0.165V$$

This margin must accommodate regulator error, wiring and trace drop, ripple, and transient droop.

A first-order capacitor estimate is:

$$\Delta V_c \approx \frac{\Delta I \Delta t}{C}$$

For an illustrative 0.5-A load increase lasting 10 μ s before the regulator responds, with 100 μ F of effective capacitance:

$$\Delta V_c = \frac{0.5 \times 10 \times 10^{-6}}{100 \times 10^{-6}} = 0.05V$$

This is an illustrative sizing calculation. Actual response time, capacitor tolerance, effective capacitance, ESR, and regulator stability must be considered.

The completed board must remain within the specified voltage range during measured load steps. Adding capacitance alone does not guarantee compliance.

2.8 Schematic and PCB Revision

The final KiCad design will incorporate the following revisions:

1. Remove the SEN0217 flow-sensor connection and pulse input.
2. Remove the TPS61240 boost circuit and dedicated flow-sensor 5-V rail.
3. Remove the Hall-sensor 12-k Ω /20-k Ω level divider.
4. Add the two-electrode probe connector.
5. Add the 100-k Ω excitation resistor, 100-k Ω pull-down, and ADC filtering.
6. Add the precipitation-input scaling circuit.
7. Add the battery-voltage measurement circuit.
8. Add solar input conditioning and reverse-current protection.
9. Confirm the MCP73871 variant and charge-current configuration.
10. Configure and verify battery-temperature protection.
11. Connect the TPS63031 input to the intended charger system OUT node.
12. Add ESP32 programming, reset, boot, and supply-decoupling provisions.
13. Add test points for conditioned solar input, battery, system OUT, 3.3 V, and sensor signals.
14. Check component footprints, connector polarity, thermal pads, and antenna clearance.
15. Complete electrical-rule and PCB design-rule checks before fabrication.

The final report will include circuit exports showing the conductivity interface, charger, solar input-conditioning stage, 3.3-V regulator, and ESP32 connections.

2.9 Technical Risks

Risk	Effect	Mitigation
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Low-conductivity water	Normal runoff may go undetected	Test representative rainfall water and adjust electrode geometry or sensing values
Incorrect probe placement	Water misses the electrodes	Identify the fixture's runoff path experimentally
Metal-wall contact	False water-present indication	Use an insulating carrier and verify dry isolation
Residual water or contamination	False rain or water indication	Use draining geometry, hysteresis, calibration, and maintenance checks
Delayed runoff	Premature obstruction alert	Measure arrival delay and set an appropriate grace interval
Wi-Fi unavailable	Alert delivery fails	Retain pending alerts and retry with bounded attempts
Supply droop	Processor reset or failed transmission	Verify regulator layout and load-transient performance
Excessive solar voltage	Charger damage	Condition panel voltage before the charger
Insufficient sunlight	Battery gradually discharges	Measure consumption and charging; disclose autonomy limits
Water ingress	Electronics or battery failure	Seal penetrations, provide strain relief, and test the completed enclosure

3. Cost and Schedule

3.1 Cost Analysis

The budget separates **listed component prices** from **engineering allowances** for items whose exact part selection or fabrication quote is not yet available.

Prices are in U.S. dollars and were checked on **October 2, 2026**. Final purchasing costs may differ because of availability, tax, shipping, tariffs, minimum quantities, and design revisions.

3.1.1 Listed Components

Component	Manufacturer / Part number	Purchase quantity	Unit or pack price	Extended cost	Source
ESP32 module	Espressif ESP32-WROOM-32E-N4	1	\$4.99	\$4.99	[22]
Battery charger	Microchip MCP73871-2CAI/ML	1	\$2.41	\$2.41	[23]
3.3-V buck-boost regulator	TI TPS63031DSKR	1	\$2.40	\$2.40	[24]
Precipitation sensor	DFRobot SEN0121	1	\$1.99	\$1.99	[6]
Protected battery	Tenergy 30016, 2600 mAh	1	\$9.49	\$9.49	[26]
Solar panel	Voltaic P124 / Adafruit 5368	1	\$14.95	\$14.95	[27]
Polycarbonate enclosure	Hammond 1554FL2GY	1	\$21.97	\$21.97	[28]
Stainless electrode screws	Everbilt 814551, six-pack	1 pack	\$1.38	\$1.38	[29]
Candidate NTC thermistor	Stackpole TNC0603FTD10K0F338	1	\$0.12	\$0.12	[30]
Listed-component subtotal				\$59.70	

The listed prices were confirmed on the linked vendor pages. The thermistor remains a candidate pending temperature-network verification. [DigiKey](#)

The screw cost is the purchase price of the six-pack. Although only two screws are used as electrodes, purchasing the pack requires the full \$1.38.

3.1.2 Additional Budget Allowances

The following are planning allowances, not vendor quotations.

Item	Budget allowance
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Solar input-conditioning IC, passives, and reverse-current protection	\$10.00
Remaining PCB resistors, capacitors, inductor, connectors, and protection components	\$15.00
Battery holder, wiring, cable glands, insulating carrier, and mounting hardware	\$10.00
Prototype PCB fabrication allowance	\$20.00
Ground-level gutter/downspout fixture materials	\$10.00
Shipping and purchasing allowance	\$15.00
Additional allowance subtotal	\$80.00

The estimated hardware and procurement cost is:

$$C_{\text{Hardware}} = 59.70 + 80.00 = \$139.70$$

A 10% contingency gives:

$$C_{\text{Contingency}} = 0.10(139.70) = \$13.97$$

$$C_{\text{Hardware, total}} = 139.70 + 13.97 = \boxed{\$153.67}$$

The PCB and remaining BOM allowances will be replaced with actual quotations once the revised design is finalized.

University laboratory instruments are assumed to be available without a separate project purchase. No paid machine-shop work is currently assumed.

3.1.3 Cost Effect of the Sensor Revision

Replacing the inline Hall-effect sensor removes the flow meter, its dedicated boost converter, and supporting signal-conditioning components.

The conductivity probe instead uses stainless-steel electrodes and inexpensive passive components. This reduces sensing complexity and cost.

Solar input conditioning remains necessary for the selected panel. It is a correction to the solar power interface and is separate from the removed flow-sensor supply.

3.2 Schedule

The following is a **proposed schedule and division of responsibilities**, rather than a record of completed work. Dates will be aligned with the official course deadlines.

Week	Planned work	Proposed responsibility	Deliverable
Oct. 5–11	Bench-test conductivity probe and representative water; characterize runoff path; confirm solar input limits	Aryan: power; Nyle: sensor tests; Eric: firmware setup	Sensor feasibility data and updated circuit plan
Oct. 12–18	Revise schematic, select remaining BOM, create mechanical drawing, implement ADC and ULP logic	Aryan: power circuits; Nyle: mounting and communications; Eric: firmware	Revised schematic, drawings, and bench demonstration
Oct. 19–25	Complete PCB layout and review; order PCB and components; build test fixture	All members, with Aryan leading PCB review	Fabrication package and completed fixture
Oct. 26–Nov. 1	Assemble and bring up PCB; verify power before connecting battery	Aryan: power bring-up; Eric: programming; Nyle: fixture and endpoint	Working board and bring-up records
Nov. 2–8	Integrate sensors, charging, decision logic, and server receipt	All members	Integrated prototype
Nov. 9–15	Run requirement tests; refine thresholds, delay, and mounting	Nyle: trial records; Eric: firmware; Aryan: power verification	Requirements-and-verification results
Nov. 16–22	Perform regression and failure tests; measure consumption and enclosure behavior	All members	Updated results and limitations
Nov. 23–29	Resolve remaining issues and prepare demonstration and report	All members	Demonstration-ready prototype and report draft
Nov. 30–Dec. 6	Complete final demonstration and documentation according to course dates	All members	Final deliverables

Sensor feasibility will be established before PCB fabrication to reduce the risk of committing to an unsuitable electrode arrangement.

4. Societal Impact, Engineering Standards, Ethics, and Safety

4.1 Societal Impact

The Clogged Gutter Detector is intended to help homeowners identify abnormal drainage without repeatedly inspecting elevated gutters. Keeping runoff away from foundations supports building maintenance and moisture control [1].

Economically, earlier notification may help a homeowner address drainage problems before prolonged overflow causes damage. The project will not claim quantified financial savings without evidence.

Socially, the system may reduce unnecessary ladder inspections. It cannot eliminate the need for cleaning, maintenance, or professional inspection.

Environmentally, a rechargeable battery and solar-assisted charging reduce dependence on disposable batteries. The battery, PCB, enclosure, and solar panel still have manufacturing and disposal impacts and require responsible end-of-life handling.

The prototype is primarily applicable to buildings with conventional gutters and downspouts and access to compatible Wi-Fi. Different roof geometries, drainage arrangements, climates, and materials may require different calibration and mounting.

4.2 Applicable Engineering Standards

Standard or guidance	Application
IEEE 802.11 [12]	WLAN framework relevant to the ESP32's supported 2.4-GHz Wi-Fi modes
47 CFR §15.247 [13]	U.S. requirements relevant to radio operation in the 2.4-GHz band
IPC-2221C [14]	Guidance for custom PCB design
IEC 60529 [15]	Definitions of enclosure ingress-protection classifications
UL 1642 [16]	Lithium-cell safety considerations
IEEE Code of Ethics [17]	Public safety and accurate technical claims

ACM Code of Ethics [18] Responsible computing, privacy, and security

ECE 445 guidance [19]–[21] Course ethics, laboratory safety, and battery procedures

The ESP32 implements the Wi-Fi modes stated in its datasheet. Referencing IEEE 802.11-2024 does not imply that it supports every feature introduced in that edition.

The prototype will not claim independent FCC, IEC, IPC, or UL certification. Manufacturer antenna-clearance and integration requirements will be preserved. Altering an enclosure with penetrations also means that its original rating cannot automatically be claimed for the completed assembly.

4.3 Ethical Considerations

The main ethical concern is the accuracy of the warning.

A false negative could cause a homeowner to assume drainage is normal when a problem exists. A false positive could cause an unnecessary inspection. The device will therefore use the phrase “**possible gutter obstruction**” and disclose measured error rates and limitations.

Water presence does not establish that the gutter is fully clear, and water absence does not establish that a clog definitely exists. Residual moisture, light rainfall, probe placement, and sensor contamination will be included in the evaluation.

Technical claims will distinguish design targets from measured results. Unsuccessful trials and communications failures will be documented rather than excluded.

The system will transmit only information needed for operation. Wi-Fi credentials will not be included in alert packets, and authenticated encrypted transport will be used where supported. Sensor status and delivery status will be treated separately.

These practices support the IEEE, ACM, and course ethical guidance [17]–[19].

4.4 Electrical Safety

The primary electrical hazard is the lithium-ion battery. A low-voltage cell can still provide substantial fault current and may become hazardous if shorted, damaged, overheated, or charged improperly.

The design will use a protected cell, an integrated charger, temperature protection, secure battery mounting, and suitable fault protection. Cell protection will supplement rather than replace proper charger design.

Solar input conditioning will prevent the panel's excessive open-circuit voltage from being directly applied to the charger.

Only the intended sensor surfaces and electrode tips will contact water. The battery, PCB, and power electronics will remain inside the enclosure.

Before battery connection, the charger and regulators will be reviewed and tested using current-limited laboratory equipment. Battery work will follow the applicable ECE 445 procedures [20], [21].

4.5 Mechanical Safety

Initial testing will use a ground-level fixture.

The electrode carrier will be secured so it cannot fall into the downspout or materially obstruct drainage. Its shape will minimize debris retention. Any drilled openings will be deburred and sealed, and wires will include strain relief.

The system will not be installed or adjusted from a ladder during rain, snow, strong wind, or other unsafe conditions.

The enclosure, solar panel, and mounting hardware will be inspected before testing. The assembly must remain mechanically secure without creating sharp edges or loose components.

4.6 Laboratory Safety Procedures

The team will:

1. Complete applicable battery safety training.
2. Obtain the required charger and battery review.
3. Verify polarity, component selection, and programming resistors.
4. Test regulators using current-limited supplies before battery connection.
5. Verify charger voltage regulation and temperature-inhibit behavior.
6. Use the required battery safety equipment during supervised tests.
7. Separate water testing from exposed electronics and mains-powered equipment.
8. Inspect the enclosure before and after splash tests.
9. Stop testing if abnormal heating, odor, swelling, smoke, or unstable behavior occurs.
10. Record faults and corrective actions before resuming testing.

These procedures will be applied according to the current course safety and battery guidance [20], [21].

5. References

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