Mean - Variance Experiment

Infrastructure Guide:

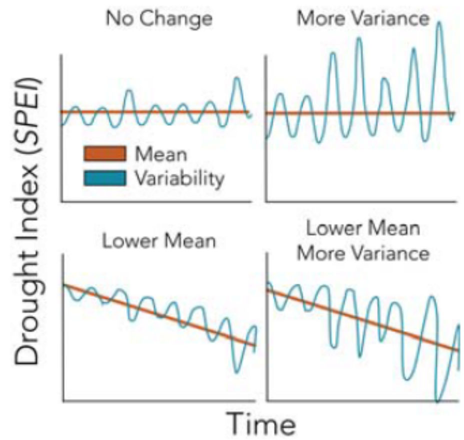
Protocols and Technical Notes

Updated by SEV-LTER staff: October 2020

Contents

Overview

Construction of the mean-variance experiment (MVE) began in 2018 as part of the NSF funded Sevilleta Long-Term Ecological Research site (SEV-LTER). The main question driving the MVE project is: **How do changes in climate mean and variance independently and interactively affect the dynamics of dryland ecosystems and the transitions among them?**



Scenarios of increases in the mean and/or variance of drought.

Figure 1 shows different drought scenarios that the MVE treatments will simulate throughout the lifetime of the project.

The purpose of this document is to detail the design, construction, and maintenance protocols of the infrastructure, sensors, and equipment involved. This document should 1) help record how and why design elements are the way they are and 2) guide insights for improvements.

The following material is not exhaustive but meant to be a living, updated document to help technicians and researchers.

Abbreviations

MVE: mean-variance experiment

MVG: mean-variance black grama site; AKA: “MVE Black”, “meanvar_black”; Chihuahuan Desert grassland dominated by black grama grass, (*B. eriopoda*); (34.334325˚ N, -106.728019˚ W); deployed spring 2020

MVB: mean-variance blue grama site; AKA: “MVE Blue”, “meanvar_blue”; Plains-Mesa grassland dominated by blue grama grass (*B. gracilis*); (34.334221˚ N, -106.630740˚ W); deployed spring 2019

MVC: mean-variance creosote site; desert shrubland dominated by creosotebush (*L. tridentata*);(34.337801˚ N, -106.738660˚ W); deployed spring 2021

MVJ: mean-variance juniper site; juniper savanna dominated by one-seed Juniper (*J. monosperma*); (GPS)

MVP: mean-variance pinon-juniper site; pinon-juniper woodland dominated by two-leaf pinon pine (*P. edulis*); (GPS)

AA: ambient mean, ambient variance (control treatment); shingles hung upside-down to allow water to enter plot

RA: reduced mean, ambient variance treatment; -25% precipitation

AI: ambient mean, increased variance (+- 50%) treatment; randomly alternating years of -50% precipitation or +50% precipitation between paired plots

RI: reduced mean (-25%), increased variance (+- 50%) treatment; randomly alternating years of -75% precipitation or +25% precipitation between paired plots

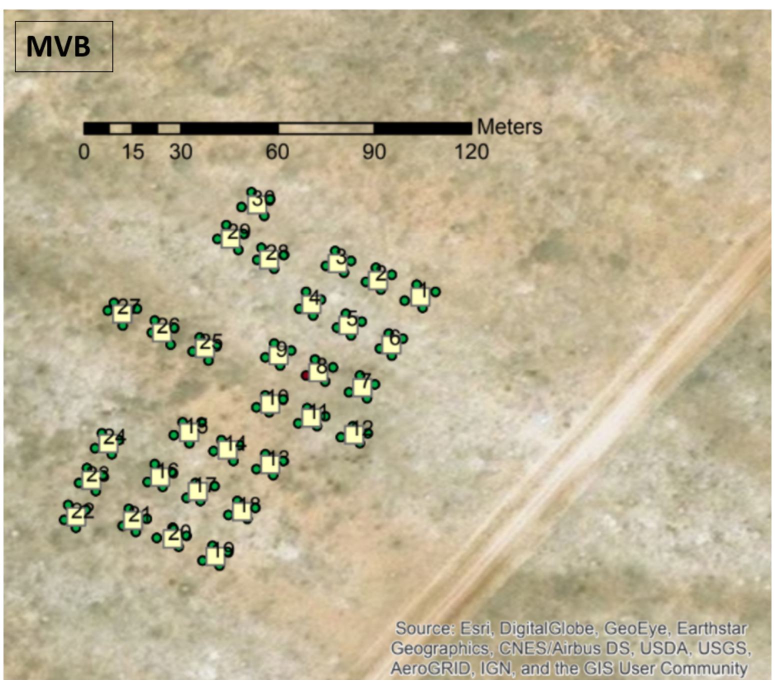
Maps and Treatments

Mean – Variance Experiment

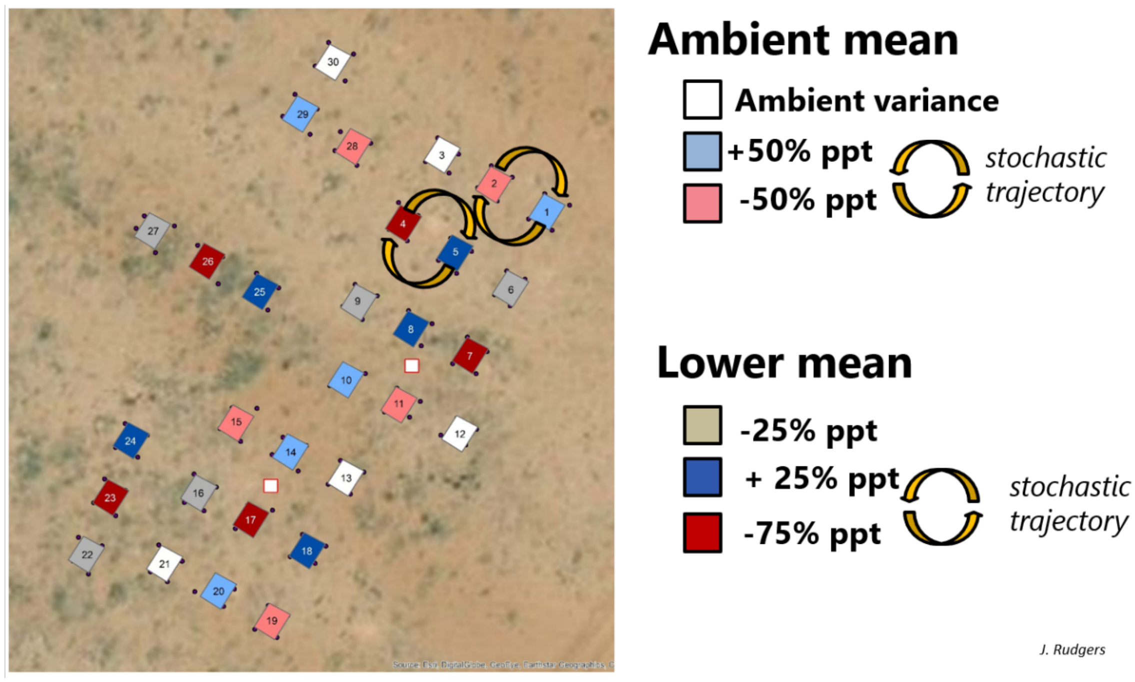
	Ambient variance mock shelter	**More variance** ± 50% precipitation
Ambient mean mock shelter	5 plots	10 plots (5 pairs)
Lower mean intercept 25% of precipitation	5 plots	10 plots (5 pairs)

J. Rudgers

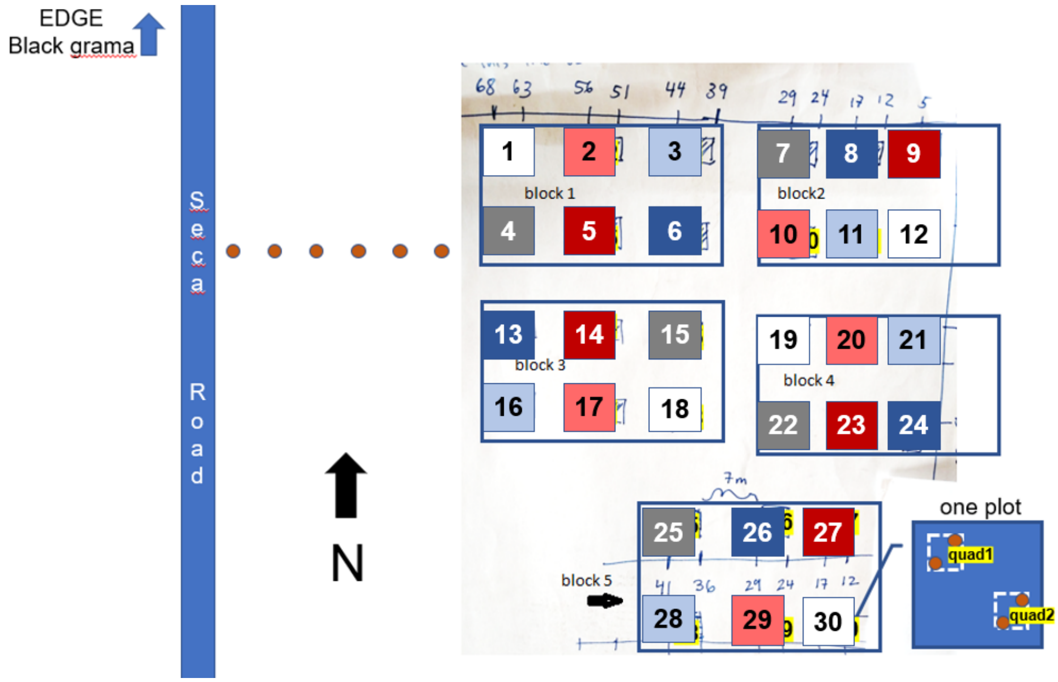
Mean variance blue grama:



MVB treatments Oct 2019 – Oct 2020

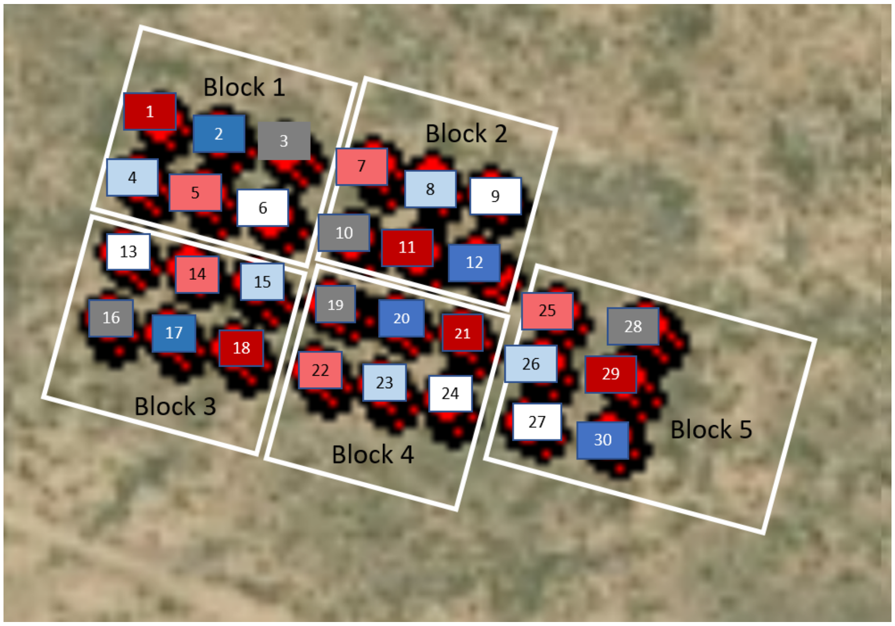


MVG treatments May 2020 - ?:



block	plot	mean_treatment	var_treatment	sensor
1	1	ambient	ambient	
1	2	ambient	increase	
1	3	ambient	decrease	
1	4	reduced	ambient	
1	5	reduced	decrease	
1	6	reduced	increase	
2	7	reduced	ambient	
2	8	reduced	increase	
2	9	reduced	decrease	
2	10	ambient	increase	
2	11	ambient	decrease	
2	12	ambient	ambient	
3	13	reduced	increase	y
3	14	reduced	decrease	y
3	15	reduced	ambient	y
3	16	ambient	decrease	y
3	17	ambient	increase	y
3	18	ambient	ambient	y
4	19	ambient	ambient	y
4	20	ambient	increase	y
4	21	ambient	decrease	y
4	22	reduced	ambient	y
4	23	reduced	decrease	y
4	24	reduced	increase	y
5	25	reduced	ambient	y
5	26	reduced	increase	y
5	27	reduced	decrease	y
5	28	ambient	decrease	y
5	29	ambient	increase	y
5	30	ambient	ambient	y

MVC treatments May 2020-?:



block	plot	mean_treatment	var_treatment	sensor
1	1	reduced	decrease	y
1	2	reduced	increase	y
1	3	reduced	ambient	y
1	4	ambient	decrease	y
1	5	ambient	increase	y
1	6	ambient	ambient	y
2	7	ambient	increase	y
2	8	ambient	decrease	y
2	9	ambient	ambient	y
2	10	reduced	ambient	y
2	11	reduced	decrease	y
2	12	reduced	increase	y
3	13	ambient	ambient	
3	14	ambient	increase	
3	15	ambient	decrease	
3	16	reduced	ambient	
3	17	reduced	increase	
3	18	reduced	decrease	
4	19	reduced	ambient	y
4	20	reduced	increase	y
4	21	reduced	decrease	y
4	22	ambient	increase	y
4	23	ambient	decrease	y
4	24	ambient	ambient	y
5	25	ambient	increase	
5	26	ambient	decrease	
5	27	ambient	ambient	
5	28	reduced	ambient	
5	29	reduced	decrease	
5	30	reduced	increase	

Protocols

Bending shingles

Shingles are made of clear acrylic (1/8” thick x 5” wide x 8’ long) and will arrive in a pile of pre-cut strips. **Two people are required during the bending process** and it should take approx. two minutes to bend a single shingle. This is a very labor-intensive step, which is often assigned to student employees of the Rudgers-Whitney lab. It should be started well in advance of the planned site deployment date.

Supplies needed: 8’ heat strip, wooden molding frame, 2 water containers, 2 large sponges, protective gloves

Steps:

1. Strip off the paper packaging of each shingle. **Hint**: 1 person doing this for a pile of shingles before moving on to bending is helpful
2. Plug in the 8’ heat strip and allow it to heat up (~10 mins), while setting up a working space including containers of water and sponges
3. **With 2 people at each end (each wearing protective gloves)** lay the shingle directly on top of the heat strip
4. As the shingle heats up, apply a gentle downward force on the sides so it begins to bend in the middle
    a. ~30 seconds of heating and bending so the entire length of the shingle is bent as evenly down the center as possible
    b. If the acrylic starts to burn or bubble you are heating it for too long!
5. Remove the shingle from the heat strip and quickly transfer it to the wooden mold
6. Insert the shingle facing down “λ” into the mold and ensure it is sitting level and fully between the blocks
7. Use wet sponges up and down the shingle to cool the acrylic down (~15 seconds)
    a. Once cooled, the shingle will keep its new V-shape

Make a pile of bent shingles and repeat steps 3-9

Marking Plot Corners

The most accurate way to mark out plot locations tends to be the traditional string and stake method used by construction contractors. This should be one of the first steps taken (before installing flashing, and then again when installing posts), and should be done carefully to save trouble during future steps. This is especially true when installing the posts. Measuring is not possible with one person, and is best with teams of two to three.

Supplies needed: large metal framing square (at least 1” x 1” - bigger is more accurate), string, measuring tape, four wooden stakes, pin flags

Steps:

1. Determine a baseline for the plot. This line should be relatively free of obstructions (trees, shrubs, large cactus), especially in the corners, as the other lines will be measured off of it. If there are sensors, subplots, etc. already installed, try to imagine how the plot will fit around them. This could save you time making adjustments later. The edge of the plot should be at least 20cm away from any sensors, subplots, or obstructions to allow room for the trencher.
2. Stake one corner of the baseline, and then measure out 5m and stake the other corner. Run a string from one stake to the other to mark the baseline. **All measurements should be taken from the outer corner of the stake for consistency and accurate angles.** Similarly, the string should run along the outside of the stake relative to the plot to be able to properly determine the angle.
3. Position the framing square on one corner of the baseline. Run a string from the outside of the stake in this corner, approximately 90˚ from the baseline, and then adjust the string and the square until both the baseline and the new 90˚ line are perfectly square. Use a pin flag touching the string to mark a point along the new line, so you don’t have to hold the string perfectly still while measuring. **Be careful with this step -- misreading the angle by a single degree will change the location of the next corner by almost 10cm.**
4. Measure out 5m along the new line, using the pin flag as a guide. Mark the intersection of the line and the 5m point using another flag, then remove the angle reference flag.
5. Replace the new corner flag with a stake, making sure that the flagged point is in the outside corner of the stake.
6. Repeat steps 2-5 to create a third side off of either the baseline or the line you just created (whichever is less obstructed).
7. Three measured sides should be sufficient to place all four corners, but you will need to check that the remaining unmeasured side is indeed 5m. If the distance between flags varies from 5m, check the angles of the other sides again. If the angles are ok, check the distances.

Flashing Installation

Aluminum flashing will be installed into the ground around the plots as a barrier to prevent ambient groundwater from seeping in.

Preparing beforehand: The flashing will need to be purchased in advance or special ordered; 50ft rolls are available for $20-25 at Home Depot and Lowes, but in limited quantities and may require several trips to different stores around town.

The process also requires rental of a trenching machine (see supplies info at bottom of section). Reimbursement for the rental requires prior approval from UNM accounting.

Supplies needed:

For trenching: a trenching machine (rented from Home Depot -- use the smallest trencher possible to minimize disturbance, but may need a larger one for rocky sites), extra gasoline (unmixed), trenching shovel (spade is about 10cm wide, can find in FS storage room), regular shovel, measuring tape, string, chaining pins, gloves, safety glasses, earplugs.

For flashing installation: ~200 wooden stakes (approx 6 per plot x 30 plots + extras, must be 12" or longer), 2000ft of 10" aluminum flashing (20m per plot x 30 plots = 600m = 1968'), metal shears to cut flashing, staple gun with at least 700 staples, rubber mallet, gloves. Heavy pants and kneepads are recommended, if available.

Steps:

1. **Mark out a guideline for the wheel of the trencher to follow.** To figure out where to put the guideline, first measure the distance from the outside of the outer wheel (the side the dirt kicks out of) to the opposite side of the trenching blade. The inside of the trench should be 15cm in from the border of the plot, and the wheel of the trencher will be the measured distance away, so to determine the location of the guideline, subtract 15cm from the size of the trencher and place the guideline that distance further out from the plot outline.

   Example:
   Distance from inside of trencher blade to outside of outer wheel (measured): 18cm
   Distance from plot boundary to inner trench wall (standard): 15cm
   Distance outside of plot boundary to place trencher guideline: 18cm - 15cm = 3cm

2. **Use trenching machine to trench the plot** (1 person)
   https://www.youtube.com/watch?v=TDuP8khAsa4
   TIPS: Wear gloves to hold trencher handle, and use goggles, earplugs, and long sleeves for PPE
   - Make sure trencher is oriented to throw soil OUTSIDE of the plot
   - Begin with saw blade raised and slowly lower using the crank (turn crank Right)
   - Lower blade to taped mark on the trencher so that depth remains consistent
   - Keep throttle fully engaged as you move the trencher, following the guideline with the edge of the wheel.
   - If you hear a rock, or the blade gets stuck, raise the blade immediately using the crank (turn crank Left), then wiggle the trencher and re-lower the blade
   - At each plot corner, turn crank Left to lift saw blade, then release throttle and swivel trencher machine 90 degrees. Re-lower the blade and begin next plot side of trenching.
   - Get a second person to help lift trencher over the sensor wires – avoid wires!

3. **Complete trenching by hand.** Use a trenching shovel and hand shovel to finish corners, hand-trench around any obstacles not navigable by the trencher, and remove back-filled dirt.

4. **Install flashing into the trench** (2 person) Do not touch flashing without gloves on
    - Use cutter to release tape on flashing
    - Line up the flashing against the edge of the trench closest to the plot – this is where the trench is most vertical and makes the flashing straighter.
    - Start the flashing by stapling a stake on to the flashing with the tip of the stake pointing down, and hammer into the ground to secure flashing into corner. This will prevent the flashing from pulling up in the future.
    - Leave ~ 2 inches of flashing above soil surface – do not bury flashing flush to ground
    - Bend flashing at 90 degree angle at plot corners, installing a stake in each corner
    - Overlap separate sections of flashing by about 5 inches to reduce possible gaps.
    - As you install each section of flashing – have one person pull the flashing taut, and the other person backfill with soil from the mound of soil left by the trencher. Use hands or a spade to backfill soil as you kneel next to the trench. The flashing will never be perfectly straight, so don't obsess here.
    - After backfilling, step on the soil backfill area on the outside edge of the flashing to compress the soil into the trench and secure the flashing.

SUPPLIES FOR FLASHING INSTALLATION

Trenching tool rental:
The Home Depot tools rental department offers this service at approximately $150/day, with a $250 refundable credit card deposit (not all locations have a trencher for rent, so call ahead). This rental is technically a service and not a purchase, so please contact Chris Black (or other UNM purchasing rep) beforehand to get the rental approved. Tax exemption needs to be applied to the rental during check-out in the morning and not during the return, regardless of what the desk staff tells you. You will need the tax-exemption account number, as this desk won't have access to the phone number directory (New Mexico ID: 01-504447-005, Federal ID: 85-6000642).

Fall 2020: 13 inch trencher (low-disturbance for soft soils at MVC)
Landscape Ground Trencher 13inch blade
Groundsaw EZ9100 ($113 / day)
~$130 / day incl damage protection ($17)
https://www.homedepot.com/tool-truck-rental/Ground-Saw/EZ9100/index.html

Spring 2020: 18 inch trencher (necessary for caliche-heavy soil at MVB)
Model # T-4-HS18
The T-4 is a small, operator propelled, chain-type trencher designed for jobs requiring up to an 18" trench in a short period of time.
https://www.homedepot.com/tool-truck-rental/Trencher-18/T-4-HS18/
https://www.youtube.com/watch?v=DgXvEq_n2dw
https://www.youtube.com/watch?v=TDuP8khAsa4

Home Depot 2820 Coors & I 40 505-833-9900
1220 Renaissance (505) 344-1900

Flashing:

Source: Amazon: $22 per 50 feet ($0.43 per foot)
https://www.amazon.com/gp/product/B0009STHQQ/ref=ox_sc_act_title_1?smid=ATVPDKIKX0DER&psc=1

True Value: $25 per 50 feet ($0.50 per foot)
customerservice@idealtruevalue.com

Local sources: Lowe's , RAKs building supply (ABQ, Los Lunas, Socorro)

Local places that do not have it: Marco Steel, MetalDepots.com, Reliance Steel, Metal Mart, RWC building, Custom Metal, BralCo Metal, Roofing wholesale, United Aluminum, ABC supply, Tractor Supply, Home Depot

T-Post Installation

Each plot will have 9 T-Posts (six 6’ posts at the corners and center of the north and south borders, and three 8’ posts in line with the center). These posts will have brackets on them to hold the conduit in place. Installing posts will take several days, and the length of time will heavily depend on soil hardness, rocks, etc. I would recommend interspersing post-pounding with bracket installation to avoid fatigue. This step is best done in teams of two, with one person holding the post straight while the other person pounds it in.

Supplies needed:

For plot marking: large metal framing square (at least 1” x 1” - bigger is more accurate), string, measuring tape, four wooden stakes, pin flags

For post installation: 180 6-foot T-Posts and 90 8-foot T-Posts (available in these quantities at Raks Socorro and Home Depot), post pounder (FS storage room), earplugs, stepladder, level

Steps:

1. Mark the corners of the plot as directed in the plot marking protocol, adding midpoints at 2.5m along each boundary.
2. For each marked spot, place a T-Post at the flagged point, remove the flag, and use the post-pounder to drive the post in two feet deep (leaving the tops of the 6’ posts at 4’ tall and the 8’ posts at Cyrus height) **To best accommodate brackets and guy wires, posts should be installed with the bumpy side facing out of the plot, towards the east or west.**
3. Readjust post with the level as needed while pounding to ensure it is as close to plumb as possible.

Brackets

Mounting the brackets can be done as soon as the posts are up. One person could install the brackets at a site in a day, once they have all the materials they need. Prepping the materials should take about a day but the angle-iron will need to be ordered in advance, since it’s in such a large quantity. Angle-iron is measured here by the number of holes, which are each an inch apart.

Cutting conduit

A site needs 240 sticks of ¾” x 249 cm (8’2”) EMT conduit.

- 2 conduit per panel
- 4 panels per plot
- 30 plots per site = **240 conduits**

Supplies needed: measuring tape, marker, chop saw or reciprocating saw, metal grinder wheel

EMT is usually sold in 10’ sticks, hence 240’ (via 10’ sticks) needs to be purchased in bulk. The conduit was cut down to our desired lengths in the following manner:

Steps:

1. Bundle 10 sticks together with tape (usually how vendor sells them)
2. Make a mark @ 249 cm on the conduit, this is where we will cut them
3. Ensure the ends of all conduit in a bundle are even with each other
4. Cut through the bundle with a saw (circular chop saw or reciprocating saw)
5. Repeat steps 1-5 for all 24 bundles

Using a grinder wheel, smooth down the sharp edges where conduit was cut; do this for all 240 sticks.

Drilling conduit

After conduit has been cut and grinded, holes are drilled to attach shingles. Multi-purpose **PVC conduit sleeves** were made to speed up the drilling process (these should be in the storage room). Before doing the steps in this section, read more about the PVC sleeves and the accompanying material (pictures, table for conduit drilling, etc.) in the shelter design and specification section of the technical notes.

There are four categories of panels that exist across the different treatments and their accompanying conduit call for different drilling:

- Conduit that get 6 hole drills (25% shelters); qty: **40 conduit**
- Conduit that get 9 hole drills (mock shelters); qty: **80 conduit**
- Conduit that get 11 hole drills (50% shelters); qty: **80 conduit**
- Conduit that get 17 hole drills (75% shelters); qty: **40 conduit**

Supplies needed: PVC conduit sleeves, hammer, center-punch, clamps or vicegrips, drill press, 3/16” drill bit for metal, drill bit oil

Steps:

1. Insert cut conduit into the correct PVC sleeve for which you wish to drill (i.e. 25% conduit into the 25% PVC sleeve that contains 6 holes)
2. Bind the conduit and sleeve together using clamps or vicegrips so that the conduit cannot rotate or move side-to-side within the sleeve
3. Place a center-punch into the first hole of the sleeve, angling the sleeve and the center-punch as straight up as possible; hammer down on the center-punch to create a mark
4. Repeat step 3 for all holes, and remove conduit from sleeve for cutting
5. Prepare the drill press so that conduit can be held up level and moved laterally so that vertical holes can be drilled exactly where the marks were made
6. For all marks resulting from the hammer punches, drill as vertically up and down as possible without moving the conduit side-to-side with a lubricated 3/16” metal drill bit
    a. Lubricate the drill bit after every 3-4 holes drilled
7. After all holes are drilled, turn the drill press off and move one
    a. **BE CAREFUL WHEN HANDLING CONDUIT AFTER DRILLING AND WEAR GLOVES!**
    b. Drilling creates sharp spurs in the metal that will cut your hands
8. Repeat steps 1-7 for all 240 conduit
   Hint: breaking up hammer punching and drilling among people or time-blocks may speed up the process. Since there are 8 conduit per shelter in the field, it helps to bundle them in 8’s and mark these bundles accordingly (e.g. spray paint across conduit denoting a 25% shelter bundle).

Drilling Shingles

Shingles are attached to conduit to make up the panels of a rainout shelter. Holes are drilled through the center of the shingle at the fold using a 3/16” drill bit at 2 5/8” (6.67 cm) from the end of the shingle on both sides. A plastic ‘drilling jig’ is made to speed up the process. Pictures of the jig and other steps in the drilling process can be found in the technical notes section of this document.

Supplies needed: power drill, 3/16” drill bit, drilling jig, work bench, scrap wood

Steps:

1. Set up a workspace with shingles to be drilled. Use a work bench with two pieces of thick scrap wood to act as a backplate so your work bench is not damaged when drilling through the shingle
2. Place the shingle facing “V-up” on your scrap wood so that it is level
3. Place the drilling jig directly on top of the shingle so that their edges align
4. Press down on the jig so that the center-fold is seated in the shingle (different shingles will have slightly different dimensions as bending process is not perfect)
5. Ensure the jig is oriented correctly so that the hole is 6.67 cm from the end of the shingle
6. Drill the hole as straight up-and-down as possible. Adjust the amount of pressure to apply accordingly so that the acrylic does not crack while drilling
   Important: make sure the hole is drilled directly in the center-fold of the shingle. If the hole sits off to the side on the flat face of the shingle it will not function properly in the field (see step
7. Repeat steps 2-6 on the other end of the shingle and move on to the next one

Flipping treatments

To simulate environmental stochasticity between paired plots, a 'coin flip' determines whether a treatment flip will occur between the 10 pairs of plots (5 plot-pairs comprising AI; 5 plot-pairs comprising RI). As of 2020, the treatment flips are expected to occur every year in late October. October 2020 is the first ever MVE flip - at MVB (Oct 2021 will include MVB + MVG; Oct 2022 will include MVB + MVG + MVC and so on..)

Note: at future site flips, carriage bolts do not need unwinding (hooray!) because they are secured via pins. **As of Oct 2020, the steps for a site flip are below.**

A minimum crew of 3-4 and a max crew of 6-8 should be a good number of helpers for 1 site per day.
Tools: gloves, 7/16" wrenches, 9/16" wrenches, phillips head screwdrivers, pliers, wire cutters, wire-tie, zipties, irrigation cutters, and extra irrigation parts in case repairs are needed

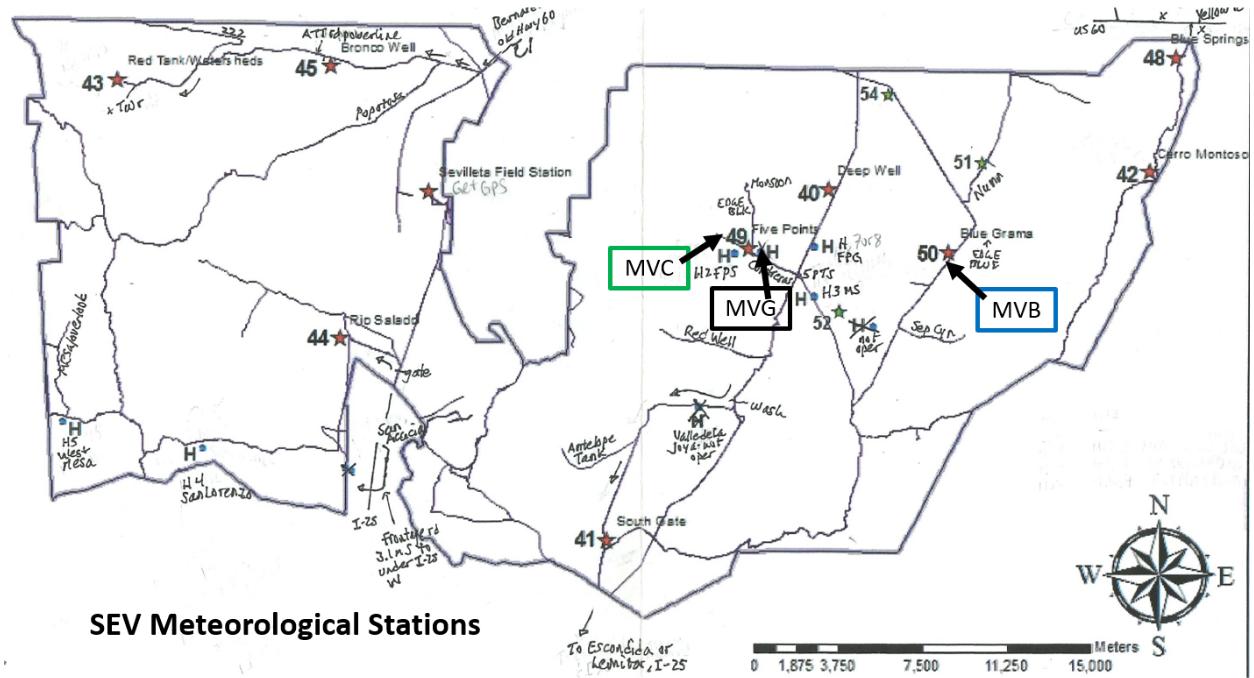
A site treatment flip will involve the following steps for all plots needing a flip:

1. Starting at one of the plots within a pair, wearing work gloves loosen all four guy wires via turnbuckles until some slack is felt in the wire; should not take more than 5-10 rotations of each turnbuckle (2 people)
2. If applicable, untie and/or uncut the irrigation line that is hanging off the conduit and set it aside
3. To remove a panel, begin unwinding the 2 carriage bolts on the outside ends of the bracket/conduit juncture (1 person per bolt). Use a 9/16" wrench to hold the nut and a 7/16" wrench to wind at the base of the carriage bolt
4. When bolts are removed, or loosened enough to pull of conduit, two people should position themselves at the center of both conduits that make up one panel (or one 'quadrant'). As a third person helps lift and remove conduit ends, the two "carriers" will simultaneously pull the panel off of the middle T-post carriage bolts, taking care not to drop or wildly shift the panel around which could break the shingles.
5. Walk the panel over near a flat spot on the ground near, but not in the way of, the paired plot
6. Repeat steps 3-4 for all four panels on plot 1
7. Now begin removing panels on the paired plot by repeating steps 1-4 while an extra person stays at plot 1 to re-tighten all 9 brackets as needed (brackets may have loosened over the previous year; use two 9/16" wrenches for this)
8. As the panels on the plot 2 are removed, the two carriers will walk them directly to plot 1 and begin sliding the panel onto the inside T-posts of the respective quadrant of the new plot where the panel was removed (Southwest panel on plot 1 should be the Southwest panel on plot 2).
    a. A third person - "the wrangler" - should help the two carriers guide the panel into place (e.g. sliding the carriage bolt into the conduit).
9. Once swapped panels are sitting on the brackets, tighten (wind-inward) the carriage bolt (or in the case of pin retrofitting drill new pins; if pins are already in place re-insert them). Repeat step 8 for all four panels and tighten carriage bolts
10. Re-tighten the guy-wires on the newly swapped plot with its four new panels
11. Repeat steps 8-10 for all four panels that were removed from plot 1 and placed on the ground next to plot 2

12. **At this point the panels have been flipped.** However the irrigation needs to be rotated. Use wire cutters to remove the hanging PVC gutters from the brackets, detach the gutter hoses from the rain barell, and and walk the gutters over to the new capture plot.
13. Using 12-gauge or thicker solid wire, tie the gutters to the new brackets
14. Finally, using as many people as needed, rotate all components of the irrigation system (pump, hoses, rain barrel, etc.) 180 degrees so that it will now be collecting and irrigating from the newly flipped plots.
15. Re-hang the gutters and irrigation lines in identical fashion of the original irrigated plot, ensuring to place the sprinklers in a way that the “T-post shadow” will not affect one of the veg sample quads.

Sensors

MVE sites are all equipped with a variety of ecological sensors to monitor effects of the environment and experimental treatments. Most important are the soil moisture and temperature sensors, which are covered in the next section. For meteorological information, MVE sites utilize existing networks of weather stations that have been collecting SEV data for decades. MVE air temperature and precipitation data, for example, is accessed from those weather stations closest to the experiment. MVK and MVC conditions are inferred from Met 49 and MVB conditions from Met 50 (see map below).



SEV Meteorological Stations

Soil moisture and temperature

The ‘soil moisture and temperature’ section will be a combination of technical notes and protocols to explain how the sensors have been deployed. This section is not exhaustive but meant to assist in future maintenance, improvements, and publications.

The jist

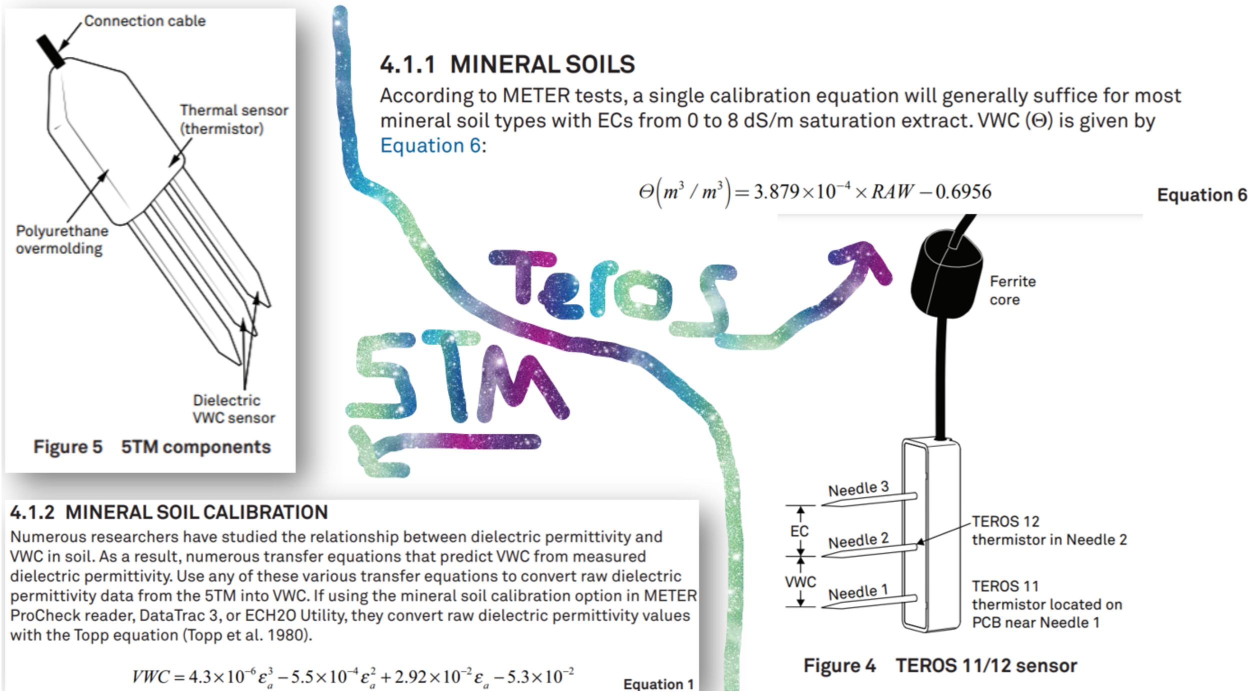
Automatic, continuous measurements of soil moisture and soil temperature are made at MVE using sensor-probes buried beneath the plots. Sensor data is averaged and recorded every 30 minutes. Each MVE site collects data in 18 of the 30 plots. In each of these 18 plots, three depths in the soil profile are equipped with a sensor: 12.5 cm, 22.5 cm, and 37.5 cm beneath the soil surface; this makes for a total of 54 sensors per site. Because sites are arranged in plot ‘blocks’ comprising the 6 distinct MVE treatments, sensors are installed into three centrally located blocks, with three representatives of the 6 treatments. Put another way: 3 sensors per plot X 6 plots X 3 blocks = 18 plots and 54 sensors; 3 of each treatment e.g. reduced mean, increased variance). Unlike the MVE paired plot treatments, sensor remain at fixed plots and do not get moved; see the ‘Maps’ section of this document for more info on where the sensors are located.18 plots per site (three per treatment) are equipped with soil moisture sensors at the shallow, medium, and deep layers.

<u>5TM vs. TEROS 11</u>

Back in my day we didn’t have any fancy sensors. We measured soil moisture with a stick and a farm hound (that’s another thing – dogs were fer workin’ not sittin’ on laps). But now that we use sensors, companies always buy each other out and constantly upgrade their models so that the one you have is obsolete. But we should be greatful in the long run because the new model, TEROS11 is way easier to install into the soil (if you can call jagged plates of CaCO3 soil) on account of the stouter, sharper pins that are inserted sideway (see pic below). But that is a word of caution: BE CAREFUL HANDLING TEROS SENSORS AS THE **PROBES ARE VERY SHARP!**

The measurements (VWC,temp) are very similar between the 5TM (old) vs. TEROS 11 (new) sensors, and their wire array is even identical, making the wiring protocols exactly the same (below). However, **the 1 big difference of old vs. new** deals with the programming protocols: the sensors have different soil calibrations and hence will need to be programmed with their respective conversion equations (pic below).

5TM (old, left) vs. TEROS 11 (new, right) sensors

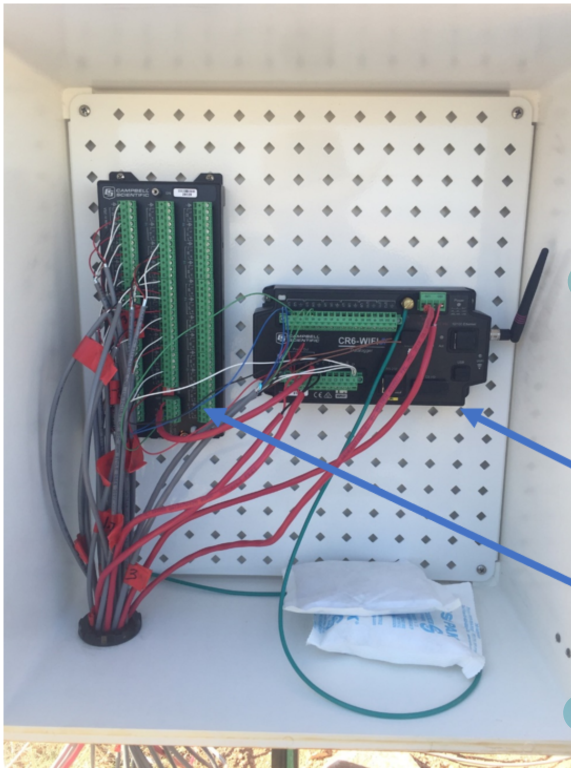


Installation and setup

The material below is all in picture form, taken from a previous document. The information is therefore specific to the point in time where the pictures are derived, e.g. installing the old-model sensors (5TM) at MVB in October 2018. Still, the material is largely adaptable for all MVE sites – sometimes without any changes. It will give technicians with little sensor experience valuable hints on maintenance, installation, etc.

Searchable keywords for this section that will be covered in the pictures below: **data; sensors; programming; wiring; wire; cables; soil moisture; Loggernet; datalogger; campbell; splicing; program; multiplexer; wireless network; CR6**

Data collection



Overview: A solar panel charges a 12V battery (via charging regulator); the battery powers the datalogger; the datalogger powers the sensors and collects measurements as the sensors perform their functions (as executed from the program uploaded to the datalogger); the datalogger stores the data collected from this process

- CR6-WiFi datalogger (Campbell Scientific) is used at BlueGrama which provides 2 useful perks: (built in router for connecting to Sev servers & built-in charge controller)

Datalogger: controls sensor measurements, collects and stores data, transmits that data remotely to SEV servers

Multiplexer (aka: **mux**): helps accommodate all of the sensors onto a single datalogger which would otherwise not have enough terminals; the muxes are connected to the datalogger, whereas the sensors are plugged in to the muxes

Antanna for radio connection

Datalogger etc. housed in weatherproof enclosure, 'u-clamped' to a t-post

South-facing solar panel (100W) wired to datalogger (or otherwise to a charge controller)

"Action packer" houses the battery (>45 amp-hour rated deep cycle battery)

Panel rests on the ground, with plywood underneath as barrier from mud, grass, etc.

CR6-WiFi datalogger: system power and wireless network connection

Following the mounting of the dataloggers into weatherproof boxes, but preceding the sensor wiring/programming, it is a good idea to check that the power systems are powering the datalogger as expected.

The following steps should be done to power the datalogger (pre-sensors) and connect it to the server (whenever):

1. Ground the system via connection from ground lug to a grounding rod hammered into the ground
2. Disconnect the green power terminal from the datalogger
3. Connect the positive (+) and negative (-) wires of the battery into their respective channels (BAT) on the power terminal
4. Connect the positive (+) and negative (-) wires of the solar panel into their respective channels (CHG) on the power terminal
5. Using a volt meter, assure channels are receiving voltage readings that make sense (12-14V). If so, plug the terminal back in to the datalogger
6. Connect an antenna to the side of the datalogger
7. Using a connection cable and the Loggernet software, connect a laptop to the datalogger and follow the instructions pasted below from the CR6 manual. Note: network information such as addresses and passwords are needed in advance)

3.1.5.4 Configuring data loggers to join a Wi-Fi network

By default, the CR6-WIFI is configured to host a Wi-Fi network. To set it up to join a network:

1. Ensure your CR6-WIFI is connected to an antenna and power.
2. Using Device Configuration Utility, connect to the data logger.
3. On the **Deployment** tab, click the **Wi-Fi** sub-tab.
4. In the **Configuration** list, select the **Join a Network** option.
5. Next to the **Network Name (SSID)** box, click **Browse** ... to search for and select a Wi-Fi network.
6. If the network is a secured network, you must enter the password in the **Password** box and add any additional security in the **Enterprise** section of the window.
7. Enter the **IP Address, Network Mask**, and **Gateway**. These values should be provided by your network administrator. A static IP address is recommended.
   - Alternatively, you can use an IP address assigned to the data logger via DHCP. To do this, make sure the IP Address is set to `0.0.0.0`. Click **Apply** to save the configuration changes. Then reconnect. The IP information obtained through DHCP is updated and displayed in the **Status** section of the **Wi-Fi** subtab. Note, however, that this address is not static and may change. An IP address here of **169.254.###.###** means the data logger was not able to obtain an address from the DHCP server. Contact your network administrator for help.
8. Apply your changes.
9. For each data logger you want to connect to network, you must follow the instruction in Setting up Wi-Fi communications between the data logger and the data logger support software (p. 25), using the IP address used to configure that data logger (step 7 in this instruction).

5TM soil moisture sensors

- **ECH2O 5TM soil moisture and temperature sensors** from Meter Group (previously company was called Decagon which you might also see)
  - Reading the manual is recommended; here is a link to the website: https://www.metergroup.com/environment/products/ech2o-5tm-soil-moisture/

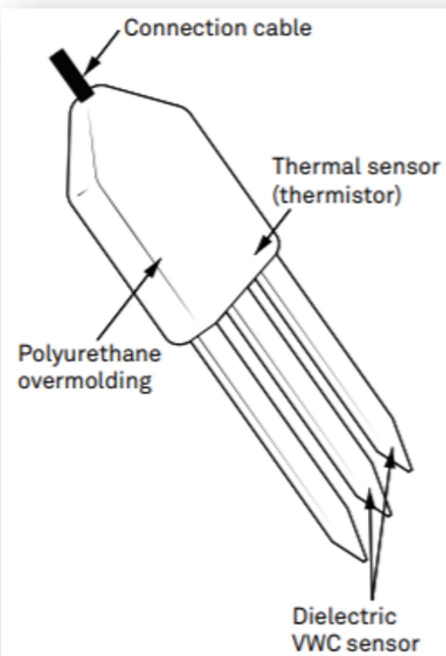


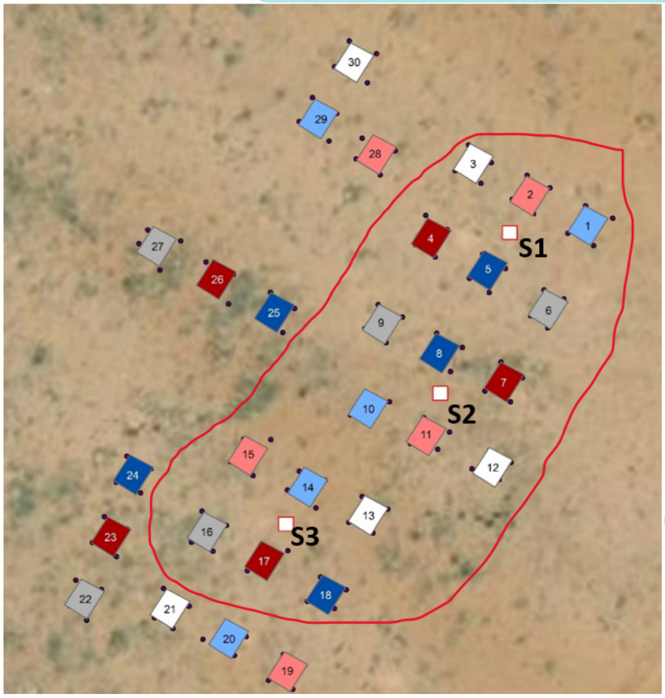
Figure 5 5TM components

Protocol for 5TM installations

1. **Establish 'stations'**
2. **Install sensors**
3. **Extend cable (wire splicing)**
4. **Integrate sensors w/ datalogger**
   - **Programming**
     - **Overview**
     - **Short Cut**
     - **CRBasic**
   - **Wiring**

1) Establish stations

- **Stations –** i.e. the infrastructure which houses the datalogger (in which the sensors are wired-in)
- Usually consists of weatherproof enclosures, solar panels, batteries, radios/antennas etc.



- Stations at Blue Grama (left) were set up in a way that made sense spatially depending on plot layout
- At Blue Grama, plots 1-18 received 5TM sensors (3 sensors per plot)
- **Stations** (S1 – S3) are represented by the white boxes
  - **S1* (plots 1-6):** datalogger; mux 1; solar panel; battery; antenna
  - **S2 (plots 7-12):** mux 2
  - **S3 (plots 13-18):** mux 3

*****S1 contains the datalogger which ultimately controls all sensors, muxes, data storage – hence additional materials for power, wireless network, etc. are located here

2) Install sensors

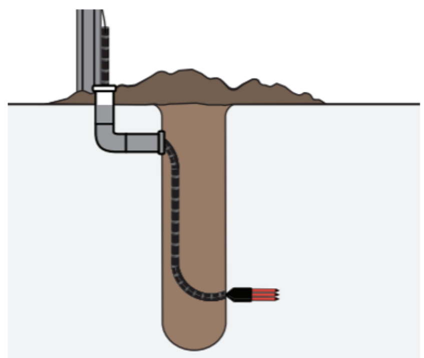
At Blue Grama, plots 1-18 received 5TM sensors. Each plot has a sensor at 3 depths (making a total of 54 sensors at the site):

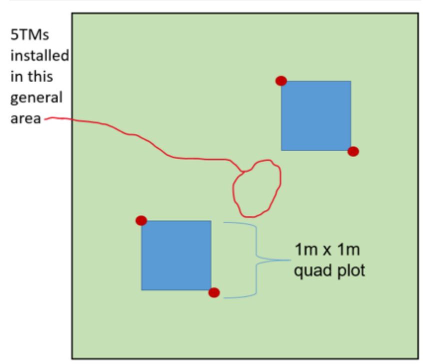
  - **12.5 cm**; **22.5 cm**; **37.5 cm**

- Each sensor records soil moisture (volumetric water content – **VWC m^3/ m^3**) and soil temperature (**degrees Celsius**)

The following steps are done at each plot:

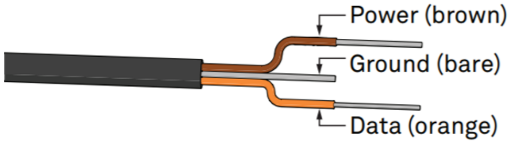
1. Mark a point slightly offset from the center (center=even distance between the 1x1 m sampling quads)
2. Avoiding obstructions (i.e. plants), dig a hole at the mark
   - Holes should be no bigger than needed to minimize disturbance (<40cm deep x ~1' wide)
   - Use a 5 gallon bucket to hold the shoveled dirt
3. Starting from the deepest depth (37.5 cm) and working up, insert each sensor horizontally into the soil on the **upslope** facing wall of the hole
   - Light force may be necessary as soils are dry and compact
   - Use a tool/knife to loosen up any problematic or rocky portions of the soil to ease insertion
   - If one spot doesn't work, move laterally along the same depth (sticking to the upslope wall if possible)
4. Label each cable (e.g. duct tape w/ plot # and sensor depth) and then backfill the hole using the collected dirt making sure to carefully compact the soil around the sensor



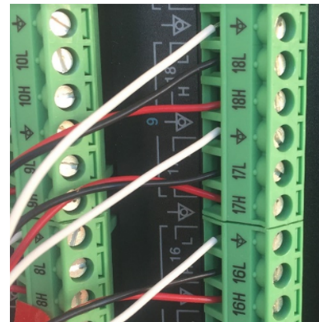


5m x 5m plot

3) Extend cable (5TM wire splicing)



Belden 709sc non-crimp splice connector



5TM sensors are three-wire cables that come with a clear, brown, and orange wire, which are extended to the datalogger using generic 3-conductor wire (pictured above)

The following steps are done for each 5TM sensor:

1. Strip off the plastic coating on the sensor cables and 3-conductor cable to expose 2-3" of individual wires
2. On each wire, strip the coating to expose just a small amount of bare wire (~1mm)
3. Insert sensor wires into Belden connector, make sure they are fully inserted and clamp down with pliers to ensure tight clasp
4. Repeat the clamp down on the other side of the Belden connector ensuring that color to color connections remain consistent; in the case of 5TM (and TEROS!) models:
   - **Brown to Red; Orange to Black; Clear to White**
5. To waterproof, tightly wrap the entire splice with electrical tape so that none of the work is showing. Finally, coat the splice – tape and all – with 'liquid electrical tape'; this will ensure protection against moisture getting into the electrical components

3) Extend cable (split loom)

To avoid damaging cable from sunlight, trampling, animals, water, etc.

1. Once connections are made, gather common groups of cable together (i.e. the three 5TM cables that run from the plot to their respective multiplexer)
2. Cut appropriate length (from plot to mux) of **UV-resistant** split loom for this group of cables
3. Using the split-loom tool (orange tool pictured below), insert all cables into the split-loom
4. For further waterproofing, cables were tied to a ground stake (pictured right) at the splice point
   - This was done because in some cases, rainwater can pool up in the split loom at the vulnerable splice connections and interrupt electrical signals and hence data

4) Integrate sensors: programming overview

In order for the datalogger to operate the sensors and collect their measurements, it must be programmed to do this. While programs can be written as a simple text or word file it must be saved and uploaded to the datalogger as a file type that is compatible with the type of datalogger being used - such as a *.CR1* file for many Campbell Scientific dataloggers.

Loggernet software (*Campbell Scientific*) offers tools that make programming dataloggers such as the **CR6** at Blue Grama (also made by Campbell) a little easier.

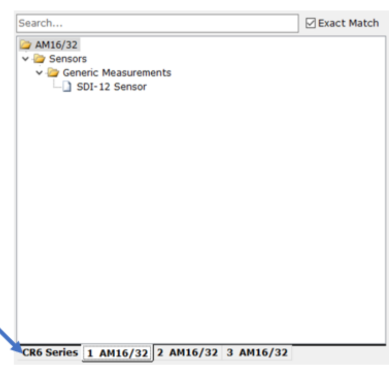
As a novice, I often create the program using the Loggernet tool ***Short Cut*** (SC). SC writes the bulk of the program for you, meaning you don't have to start anything from scratch without being fluent in 'basic'. SC should get you most of the way to having a functional program. However, if your measurements require slightly more nuance than SC can offer, you can save and then re-open the same program that was started in SC in another Loggernet tool called ***CRBasic editor*** and make edits to the existing program. This is not a 'wizard' interface like SC but looks more like a notepad with some helpful tools that explain what you are looking at. Once CRBasic is used to complete the program, it is ready to be uploaded to the datalogger.

While the above tools facilitate the process, programming still requires your knowledge of the type of sensors/loggers being used and of course the type of data you want to collect (e.g. units; time increments of your measurements). Can be confusing without programming experience but there are resources through Campbell Scientific **such as the Loggernet manual online** that make it a little easier.

The next page details the steps taken to program the MVE Blue Grama CR6 datalogger to power the multiplexers and sensors that collect 30-minute measurements of soil moisture and soil temperature.

4) Integrate sensors: programming Short Cut

Short Cut tool gets the program started. Complete the steps in the SC wizard to specify what kind of hardware/devices the system would be operating.



See 'establish stations' slide

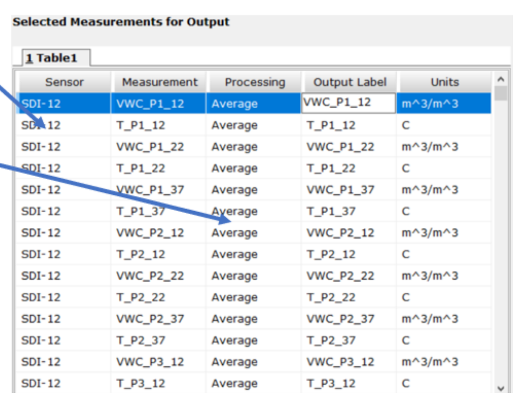
For example **Blue Grama** has a CR6 datalogger.

The CR6 powers three AM16/32 multiplexers.

Each mux contains 18 'Generic SDI-12' sensors that collect VWC and T (these are the 5TMs)

The amount of times the program makes measurements and how those data are processed (Average? Maximum?) and stored are also specified in SC

Assuming everything is done correctly: the program is compiled, saved, and uploaded to a datalogger which will begin executing its functions and measuring its sensors


Selected Measurements for Output

1 Table1

Sensor	Measurement	Processing	Output Label	Units
SDI-12	VWC_P1_12	Average	VWC_P1_12	m^3/m^3
SDI-12	T_P1_12	Average	T_P1_12	C
SDI-12	VWC_P1_22	Average	VWC_P1_22	m^3/m^3
SDI-12	T_P1_22	Average	T_P1_22	C
SDI-12	VWC_P1_37	Average	VWC_P1_37	m^3/m^3
SDI-12	T_P1_37	Average	T_P1_37	C
SDI-12	VWC_P2_12	Average	VWC_P2_12	m^3/m^3
SDI-12	T_P2_12	Average	T_P2_12	C
SDI-12	VWC_P2_22	Average	VWC_P2_22	m^3/m^3
SDI-12	T_P2_22	Average	T_P2_22	C
SDI-12	VWC_P2_37	Average	VWC_P2_37	m^3/m^3
SDI-12	T_P2_37	Average	T_P2_37	C
SDI-12	VWC_P3_12	Average	VWC_P3_12	m^3/m^3
SDI-12	T_P3_12	Average	T_P3_12	C

4) Integrate sensors: programming CR Basic pt. 1

CRBasic Editor tool can be found in the Loggernet software and was used to edit the MVE Blue Grama program created in Short Cut. CRBasic editor uses the BASIC programming language: the Loggernet manual provides some background and examples.

--CRBasic editor was used in the MVE program to convert the raw permittivity values that are generically collected by the 5TMs (programmed as SDI-12 sensors) to values that are practical for our research: volumetric water content (VWC) in units of m^3/m^3. Th permittivity value is the first of 2 values collected by the sensor and is converted via the **polynomial expression below as taken from the 5TM manual**. The second value generically measured by the 5TM sensor is temperature in degrees C, and this requires no conversion.

4.1.2 MINERAL SOIL CALIBRATION

Numerous researchers have studied the relationship between dielectric permittivity and VWC in soil. As a result, numerous transfer equations that predict VWC from measured dielectric permittivity. Use any of these various transfer equations to convert raw dielectric permittivity data from the 5TM into VWC. If using the mineral soil calibration option in METER ProCheck reader, DataTrac 3, or ECH2O Utility, they convert raw dielectric permittivity values with the Topp equation (Topp et al. 1980).

$$VWC = 4.3\times10^{-6}\varepsilon_a^3 - 5.5\times10^{-4}\varepsilon_a^2 + 2.92\times10^{-2}\varepsilon_a - 5.3\times10^{-2} \qquad \textbf{Equation 1}$$

Raw value (dielectric permittivity) measured by the 5TM sensor

4) Integrate sensors: programming CR Basic pt. 2

Right: a portion of the MVB code in CRBasic editor tool

Most of what you see was written automatically by Short Cut.

However, the VWC conversion code in **line 490** was edited manually in CRBasic.

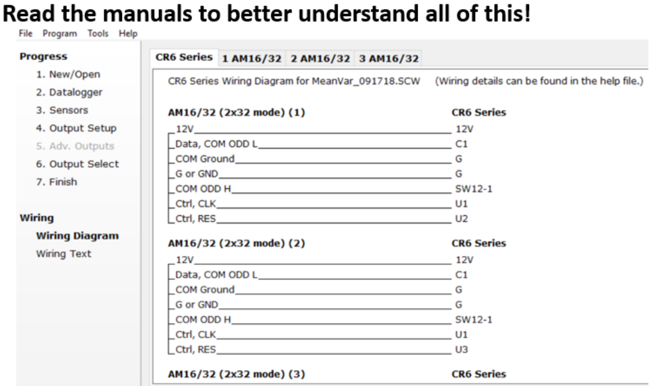
Line 490 is referencing mux 1 and hence must be repeated for the 2 remaining muxes (later lines in the code)

```
475       PortSet(U1,1)
476       Delay(0,10000,uSec)
477       PortSet(U1,0)
478       Delay(0,10000,uSec)
479       'Enable power to Generic SDI-12 Sensor
480       SW12(1,1)
481       'Allow Generic SDI-12 Sensor to warmup before polling
482       Delay(0,1000,mSec)
483       'Poll Generic SDI-12 Sensor measurements 'VWC()', and 'T()'
484       SDI12Recorder(SDI12(Count,1),C1,"0","M!",1,0)
485       'Disable power to Generic SDI-12 Sensor
486       SW12(1,0)
487       Count=Count+1
488     NextSubScan
489     For Count=1 To 18
490       VWC(Count)=4.3E-6*SDI12(Count,1)^3 - 5.5E-4 * SDI12(Count,1)^2 + 2.92E-2 * SDI12(Count,1) - 5.3E-2
491       T(Count)=SDI12(Count,2)
492     Next
493     'Turn AM16/32 Multiplexer Off
494     PortSet(U2,0)
495     Delay(0,150,mSec)
496     'Turn AM16/32 Multiplexer On
497     PortSet(U3,1)
498     Delay(0,150,mSec)
499     Count_2=1
500     SubScan(0,uSec,18)
501       'Switch to next AM16/32 Multiplexer channel
502       PortSet(U1,1)
503       Delay(0,10000,uSec)
```

When you think you are done editing, attempt to **compile** the program (by hitting the 'compile' button). If there are errors, the program will not compile properly, and the tool should point out which lines in the code are creating problems. Once you fix errors and the program compiles successfully, save the file (which should save as a .CR1 file) and you should be ready to upload the program to the datalogger which will begin taking measurements (assuming everything is wired properly – see next sections).

4) Integrate sensors: wiring

Wiring the sensors in to the datalogger will vary depending on the type of sensors used and how the program is written to accommodate the sensors and dataloggers.
--When using Short Cut to create a program for Campbell Scientific dataloggers (see ‘programming short cut’ portion of this document), the option to view a wiring diagram is available for the specified program and sensor arrangement you have chosen.
--Still, knowledge of the sensor models and the datalogger terminals should be reviewed in detail prior to connecting the cables and powering the system.
Read the manuals to better understand all of this!



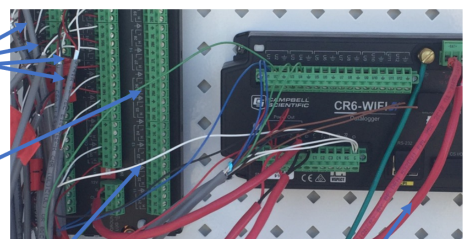
Left:
View of the ‘wiring diagram’ tool in short cut

Detailed wiring spreadsheets and datalogger programs for the various MVE sites are available online (in the shared project folders)

A closer look

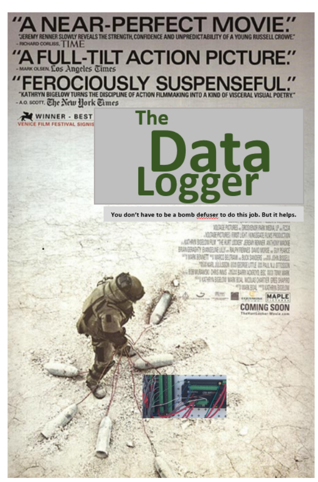
Vexation lines

The self-doubt wire



The cord of volatility

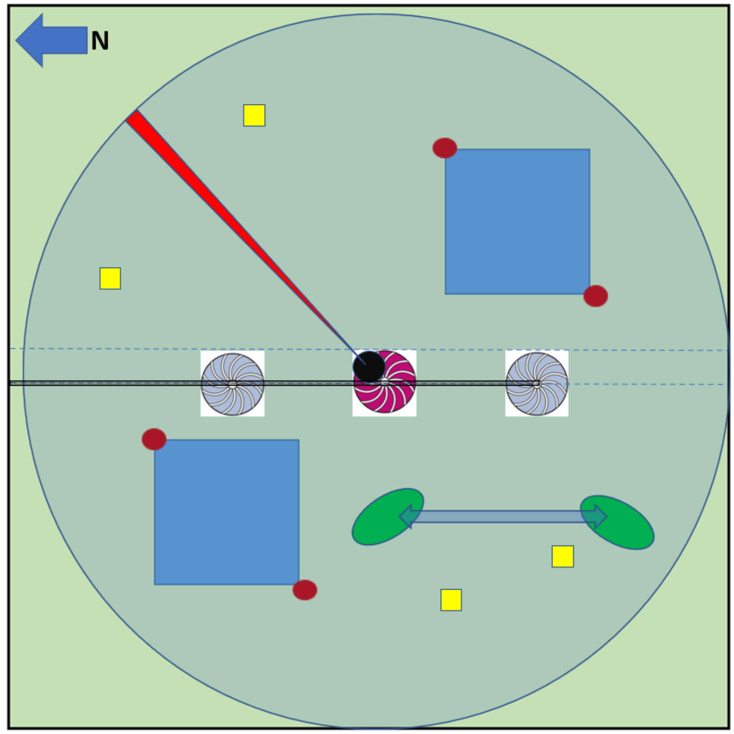
The imminent threat of explosion cable



New sensor placement (MVC)

Irrigation Footprint
(moving sensors @ MVC 2020)

MVC sensors were installed Oct 2020. Notice the new position of the placement (green oval). This was done 1) to avoid the center of the plot where T-posts are installed which obviously can conflict w/ sensors and 2) as an attempt to place the sensors in a more actively treated area, since the spray of water is more reliable in a circular band of the plot that contains the veg-quads. Here we expect MVC soil moisture data to be more representative of the amount of water received in the quads. The sensors are placed opposite the veg-quads (either NE or SW quadrants) and wherever bare ground is ample (arrow represents placement moving laterally, i.e. to avoid plants)



Sensor data

Checking the data regularly will help identify if the system is working as a whole or if there are individual sensors that need to be fixed.

2 options of downloading data: 1) remotely from the 'Socorro' server 2)manually via Loggernet

Option #1) Follow the steps below to download MVE data from the server

1) You will need the free FTP software FileZilla to access the servers, so download and install that on your computer. https://filezilla-project.org/

2) Once you have FileZilla installed:

    - Open FileZilla
    - At the top, enter the Host: socorro.unm.edu
    - Enter your Username: **get username from Sev data manager**
    - Enter your Password: **get password from Sev data manager**
    - Click Quickconnect

   Now you should be logged in to Socorro.

3) You'll see a 'Remote site' box on the right side. To get to the wireless data, enter: **/net/ladron/export/db/work/wireless and** press enter. This will take you to the directory that contains all of the wireless data folders. You can then double click on the folders to get into any of them to see the files in the folders.
4) Open the "mve" folder in the file directory for the server (upper right window of FileZilla). Depending on the site you want data from, open the subfolder (i.e. blackgrama vs. bluegrama)
5) The raw data file is a DAT file (e.g. MVE_BlackGrama_CR6.dat) – This is the file you want to download. Drag this file into the left side of your screen into the folder on your computer of your choosing.
6) When you are done downloading files, disconnect from the server. To do this, go to the icons at the top of the program. You'll see a computer looking icon with a red X, and if you hover over it, it says 'disconnects from the currently visible server'. Click that. Then, you can exit FileZilla. Now, you can navigate to the folder on your computer where you downloaded the files, and open them locally on your computer.

Option #2) Follow the steps below to download MVE directly from the datalogger

1) Download LoggerNet onto your computer and add a datalogger using the 'Setup' (EZ setup wizard)
2) After the datalogger is in your system, communicate with the datalogger by opening the 'Connect' screen
3) On the left side of the window, click once to highlight the datalogger you want to connect to and then click connect
4) From there you can set the datalogger clock, collect data, upload a program, etc.
    a. Note: dataloggers at met stations, MVE, and elsewhere around the Sev **do not abide by daylight savings time**. Set field laptops to this time (Arizona time).
    b. Click 'connect now' or 'custom collect' to download data
5) After you have downloaded data **Disconnect** in upper left when you are done

There are many ways to process the data to check for quality, make sure sensors are working, or do more elaborate analysis. R software would be a good tool for this. But the most basic way to check the data and make sure the sensors are working would be to open your downloaded file into excel, and look at each of the data values for each sensor. If you know what to look for, this will only take a few minutes per site (see pic below).

Checking data

Below is a pic of the raw data file downloaded from the datalogger (either via Loggernet or from the server). Data is collected every thirty minutes. Each Teros 11 sensor (or older 5TM sensors) deliver two values: **1)** volumetric water content as "unit-less" value of 0-1 and **2)** temperature (T) in degrees C. Hence the pattern you see below is *VWC_Plot13_ShallowDepth; T_Plot13_ShallowDepth; VWC_Plot13_MiddleDepth; T_Plot13_MiddleDepth; and so on*

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	TIMESTAMP	RECORD	VWC_P13	T_P13_12	VWC_P13	T_P13_22	VWC_P13	T_P13_37	VWC_P14	T_P14_12	VWC_P14	T_P14_22	VWC_P14	T_P14_37	VWC_P15	T_P15_12	VWC_P15	T_P15_22
2	10/31/2019 13:30	0	0.068	11.86	0.095	9.52	0.082	13.3	0.057	9.62	0.063	9.82	0.079	13.9	0.06	10.48	0.059	10.52
3	10/31/2019 15:00	0	0.069	14	0.095	10.42	0.081	13.2	0.058	12	0.064	10.34	0.079	13.7	0.061	12.28	0.059	10.88
4	10/31/2019 15:30	1	0.069	14.42	0.096	10.7	0.082	13.12	0.059	12.55	0.064	10.52	0.079	13.7	0.061	12.63	0.06	11.03
5	10/31/2019 16:00	2	0.069	14.67	0.096	11	0.082	13.1	0.059	12.95	0.064	10.77	0.079	13.7	0.061	12.87	0.06	11.18
6	10/31/2019 16:30	3	0.069	14.7	0.096	11.3	0.082	13.15	0.059	13.17	0.064	10.98	0.079	13.7	0.061	12.98	0.06	11.35
7	10/31/2019 17:00	4	0.069	14.53	0.096	11.57	0.082	13.2	0.059	13.2	0.064	11.18	0.079	13.7	0.061	12.97	0.06	11.55
8	10/31/2019 17:30	5	0.069	14.12	0.096	11.77	0.082	13.2	0.059	13.08	0.064	11.42	0.079	13.7	0.061	12.82	0.06	11.7
9	10/31/2019 18:00	6	0.068	13.53	0.096	11.92	0.081	13.22	0.059	12.78	0.064	11.58	0.079	13.7	0.061	12.6	0.06	11.85
10	10/31/2019 18:30	7	0.068	12.8	0.096	12	0.082	13.3	0.059	12.33	0.064	11.73	0.079	13.7	0.061	12.25	0.06	11.98
11	10/31/2019 19:00	8	0.068	12.08	0.096	12.07	0.082	13.32	0.058	11.82	0.064	11.85	0.079	13.7	0.06	11.83	0.06	12.1
12	10/31/2019 19:30	9	0.067	11.35	0.096	12.07	0.082	13.4	0.058	11.25	0.064	11.92	0.079	13.7	0.06	11.4	0.06	12.2
13	10/31/2019 20:00	10	0.067	10.67	0.096	12	0.082	13.42	0.057	10.65	0.064	12	0.079	13.8	0.06	10.92	0.06	12.3
14	10/31/2019 20:30	11	0.067	10.05	0.096	11.93	0.082	13.5	0.057	10.05	0.064	12	0.079	13.8	0.06	10.47	0.06	12.33

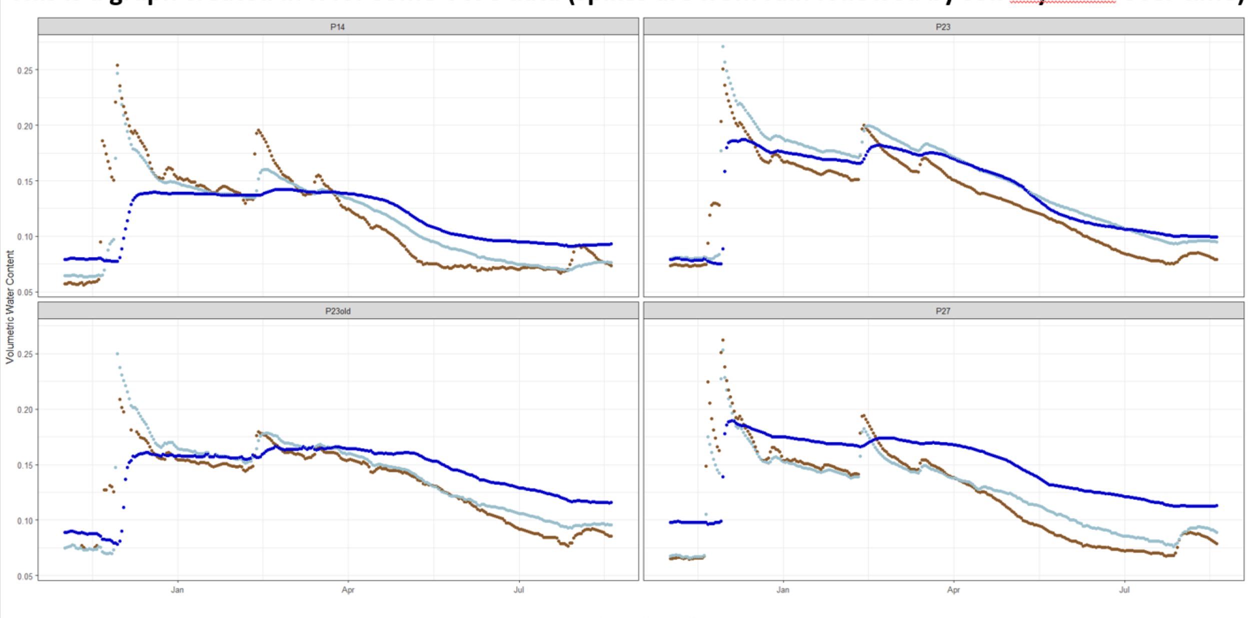
Things that would mean a sensor was broken:

-values are NaN (not a number)

-values are incredibly high or low

-values are unchanging. Values should not fluctuate very much during dry times, but even the VWC data oscillates sometimes (see column C) which is usually a good sign

This is a graph created in R for some VWC data (spikes are from rain followed by soil drydown over time)



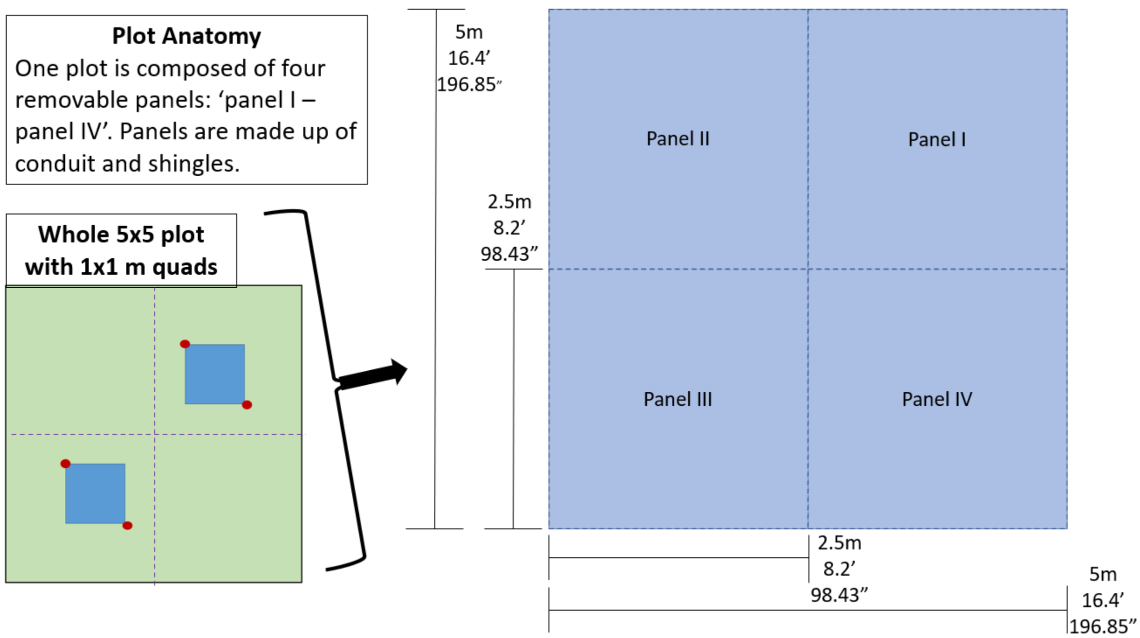
Infrastructure

Shelter design and specifications

Our rainout shelters emulate Yahdijan and Sala, 2002 whereby bands of clear acryllic shingles are positioned over vegetation plots, intercepting a certain amount of rainfall depending on the proportionate cover of the shingles. Pictured below are simple diagrams to illustrate the basic anatomy of the shelters. This will be just a simple reference before the more detailed sections about how to fabricate and install the shelters.

Overview

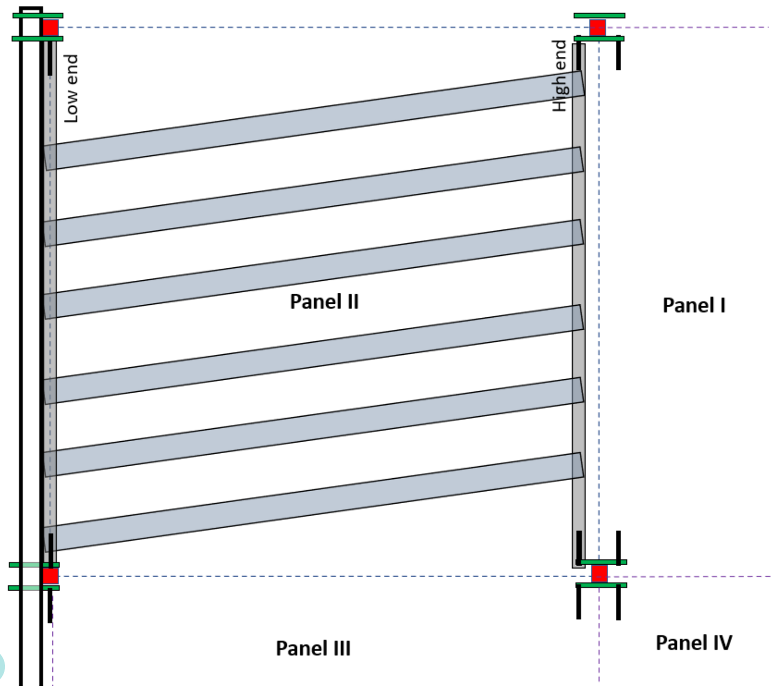
Yadda yadda blah blah

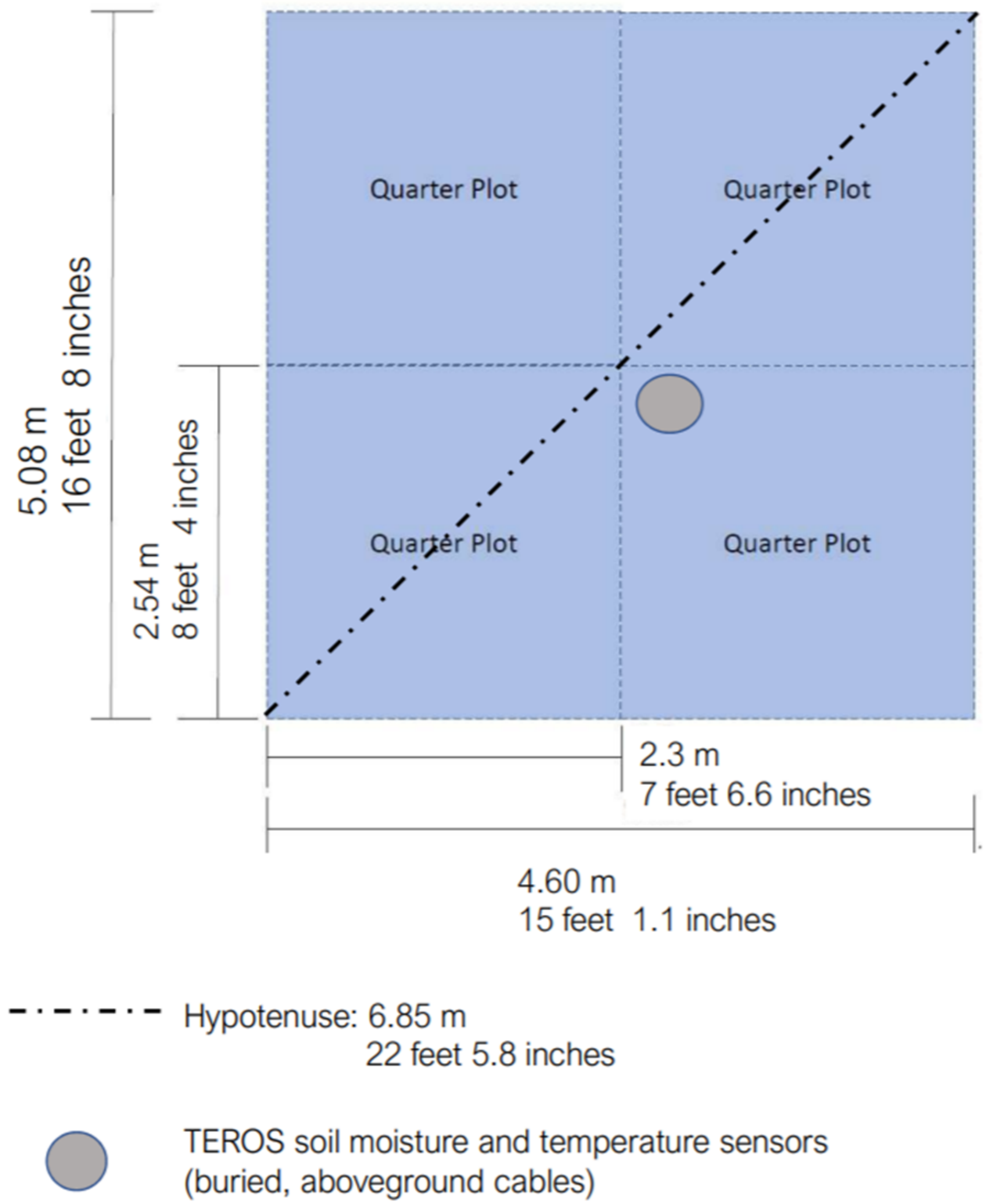


Shelter Anatomy

Key

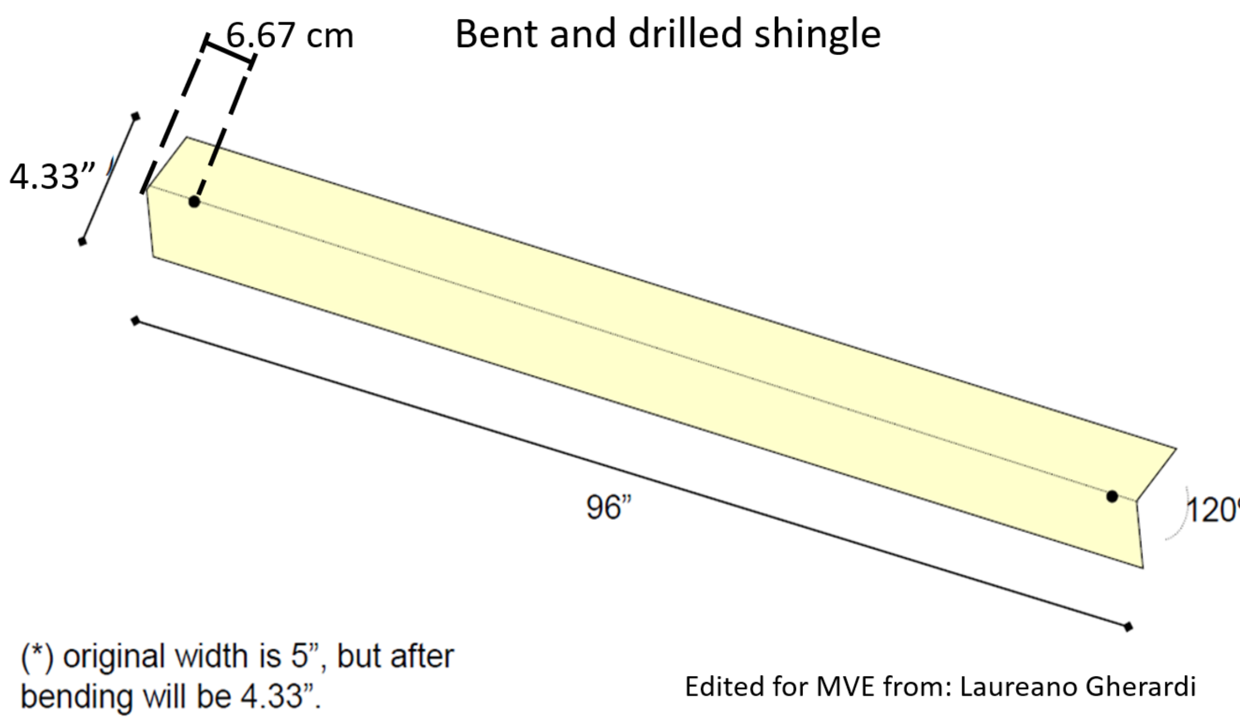
- **T-post** vertical poles supporting the structure; 9 per plot
- **Conduit** main support for shingles, sits atop bracket; 8 per plot
- **Bracket (angle iron)** binds carriage bolt and conduit to T-posts, 9 pairs per plot
- **6” Carriage bolt** helps keep conduit bound to bracket
- **Shingle** clear acrylic ‘v’ shaped clear acrylic captures rain
- **Gutter** 4” schedule 40 PVC cut in half-pipe configuration; two per plot




Quarter Plot
Quarter Plot
Quarter Plot
Quarter Plot
5.08 m
16 feet 8 inches
2.54 m
8 feet 4 inches
2.3 m
7 feet 6.6 inches
4.60 m
15 feet 1.1 inches
Hypotenuse: 6.85 m
22 feet 5.8 inches
TEROS soil moisture and temperature sensors
(buried, aboveground cables)

Shingles and panels

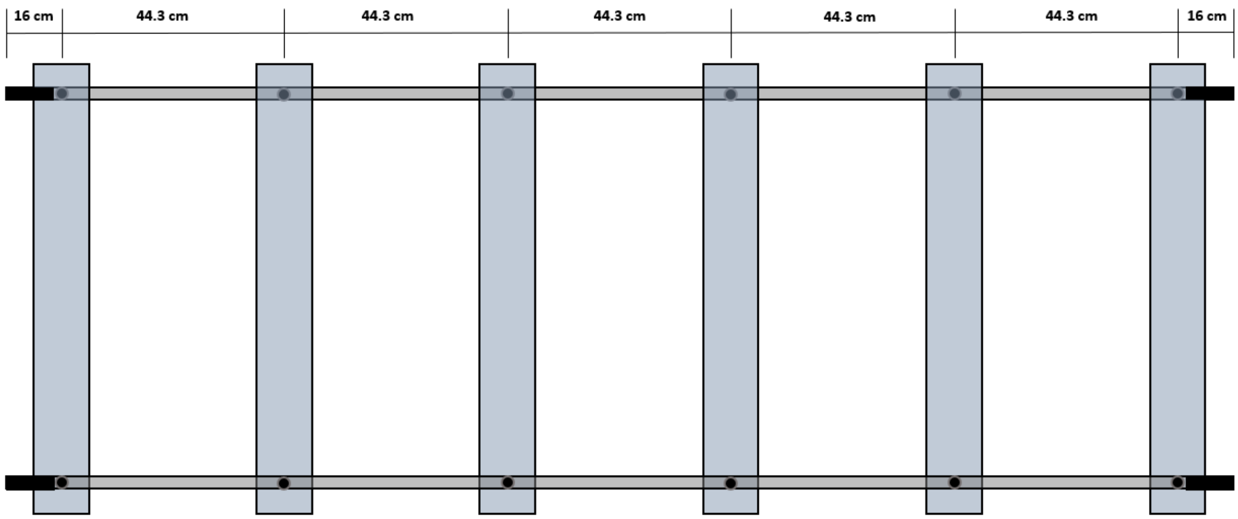
Shingles begin as sheets of clear acrylic (1/8" thick x 96" long x 48" wide). Sheets are cut down into 5" strips and bent length-wise at 120 degrees. This bend reduces the width of the shingle to 4.33" or 11 cm (see pic below). During the prototype buildout, it was determined that shingles on the high end of the shelter should attach to the conduit at 2 5/8" (6.62 cm) from the top of the shingle. This distance eliminated gaps between opposing panels (thus preventing rain throughfall) while allowing just enough room between shingles to avoid touching. To encourage uniformity and avoid confusion, the 'low end' of the shingles attach at the same point to the conduit, and hence both sides of the shingle are drilled at the same point from each end. These uniform shingle holes determine the present dimensions of the shelter T-post placement (see overview section).



Based on plot size (500 cm x 500 cm), panel size (250 cm x 250 cm), shingle width (11 cm), and the desired rainfall interception rate, the shingle configuration across a panel was a simple calculation of *((panel size * % capture) / shingle width)* and again dividing the # of interspaces for an even width between shingles. At first, an arbitrary shingle starting point on either side of a panel was determined to avoid the 6" carriage bolt which prevents a shingle being placed on top of it. This distance was 16 cm (or 6.3"). This worked ok for the 25% panels because of the ample space to work with having only 6 shingles, but caused **two problems** with the 50 – 75% panels: 1) a glaring interspace in the middle of the plot (see pic below) and 2) the lack of space prevented achieving the true capture rate based off a 5x5 m plot. **The solution** was 1) to attach shingles with a U-bolt where the was a carriage bolt holding up the panel, and 2) using a vertical pin to bind the panel to the bracket/T-post (this was originally done for maintenance resasons see ‘*removing and swapping panels’* section). Both of these options allowed shingles to be secured across the entire stretch of the conduit, allowing the acrylic edges to be virtually in-line with the edge of the conduit (**5.5 cm** at the point of shingle-conduit connection). Figures below include hole spacing calculations, and examples of configuration processes, tables, and tools.

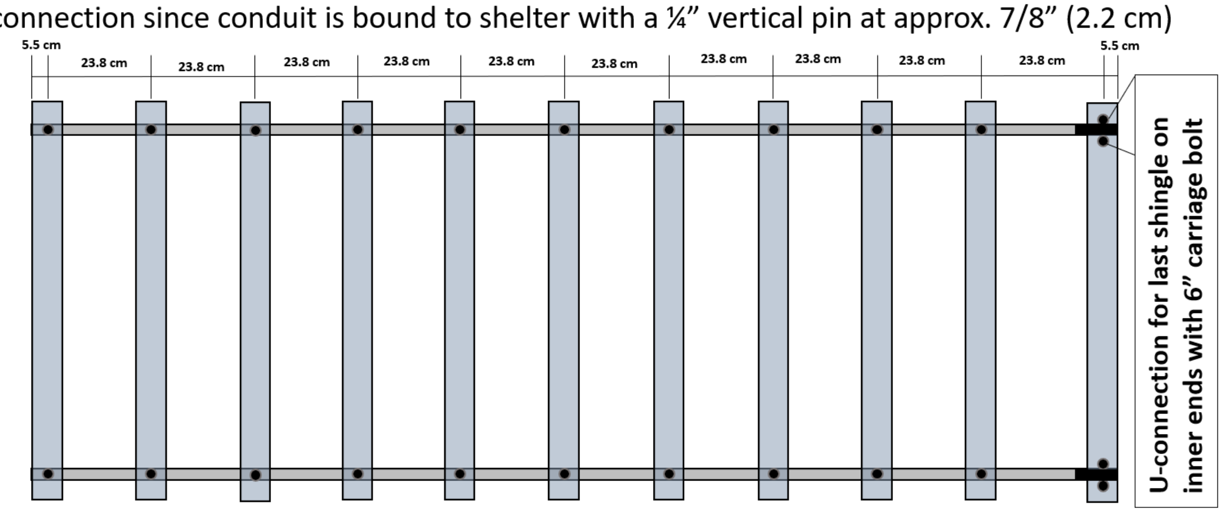
Example of 25% panel

6” carriage bolts (darkened blocks) hold panel up on all 4 sides



Example of 50% panel

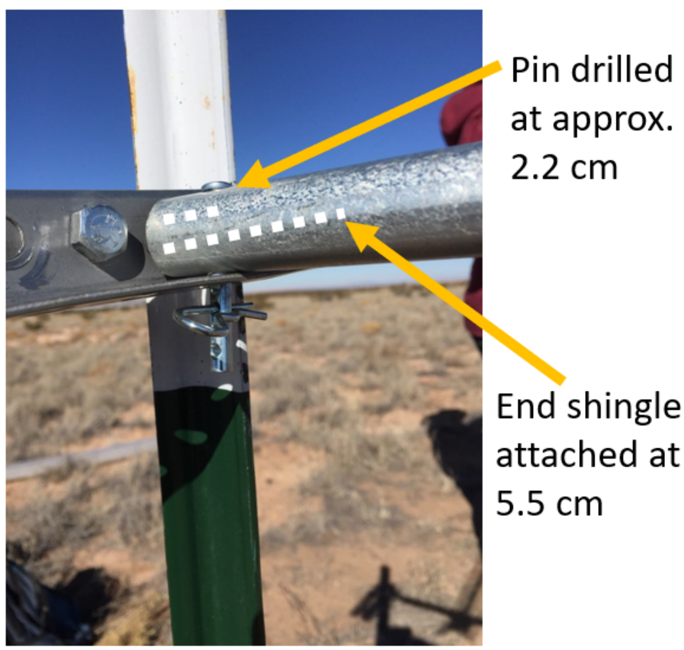
More shingles per panel creates spacing conflicts with 6” carriage bolts; thus shingles on ‘inner ends’ (right) are attached via u-bolt while shingles on outer ends (left) maintain nut+bolt connection since conduit is bound to shelter with a ¼” vertical pin at approx. 7/8” (2.2 cm)



Shingle Configuration problem (UNM Field Station prototype Feb 2019)
6” carriage bolt holding up the conduit on both ends created gaps in the middle allowing precip to move through, and left each panel 1 shingle short (4 per plot) causing false interception rates

Shingle Configuration solution

1) Fixing ‘end’ shingles to conduit via u-bolt or other u-connection to avoid carriage bolt confrontation (left). 2) binding conduit directly to brackets via pin; more details on this available in other sections of this manual



25% treatment – (250 cm plot) * (25% interception) = 62.5 cm → (62.5) / (11 cm shingles) = **6 shingles**
- Hole spacing – (249 cm tube – 32 cm) = 217 cm → (217) / (6-1) = **43.4 cm** between holes

50% treatment – (250 cm plot) * (50% interception) = 125 cm → (125) / (11 cm shingles) = **11 shingles**
- Hole spacing – (249 cm tube – 11 cm) = 238 cm → (238) / (11-1) = **23.8 cm** between holes

75% treatment – (250 cm plot) * (75% interception) = 125 cm → (125) / (11 cm shingles) = **17 shingles**
- Hole spacing – (249 cm tube – 11 cm) = 238 cm → (238) / (17-1) = **14.87 cm** between holes

Table for drilling conduit (below), which represents where the PVC conduit sleeve has pre-determined holes for a given treatment (get a pic of this). Note: PVC sleeve for the 50% conduit is also used for mock plots, but the first and last holes are skipped.

Cumulative lengths for 'shingle holes' on conduit							
25%		Mock		50%		75%	
Shingle	Hole (cm)	Shingle	Hole (cm)	Shingle	Hole (cm)	Shingle	Hole (cm)
1	16	1	29.3	1	5.5	1	5.5
2	59.4	2	53.1	2	29.3	2	20.37
3	102.8	3	76.9	3	53.1	3	35.24
4	146.2	4	100.7	4	76.9	4	50.11
5	189.6	5	124.5	5	100.7	5	64.98
6	233	6	148.3	6	124.5	6	79.85
		7	172.1	7	148.3	7	94.72
		8	195.9	8	172.1	8	109.59
		9	219.7	9	195.9	9	124.46
				10	219.7	10	139.33
				11	243.5	11	154.2
						12	169.07
						13	183.94
						14	198.81
						15	213.68
						16	228.55
						17	243.42

Shelter Maintenance

Add stuff here

A pile of extra shingles should be kept on site as replacement material after damage (esp. at MVB). Black storage containers at the sites contain extra hardware and other tools for fixing various items on site. As of Oct 2020, box at MVB has most of these items including: several wrenches and screwdrivers, hardware, extra irrigation fittings etc.

Treatment flips (removing/swapping panels)

Once per year occurring during the first week of October, the increased variance plots of MVE will undergo a randomly determined treatment assignment in order to simulate environmental stochasticity. This means that all paired plots at a site will have a “coin flip” to determine the treatment that will be administered on that plot for the rest of the water-year, until the following October.

In practice this means that each of the ten pairs of plots have a 50% chance of a treatment flip, whereby the panels, gutters, and irrigation infrastructure would be reversed to turn a capture plot into a pumped plot (and vice-versa). For the ‘reduced mean x increased variance’ treatment for example, the -75% capture plot would have its panels removed and swapped with the +25% pumped plots’ infrastructure (including the -50% panels and sprinkler irrigation system). The same principle applies to the ‘ambient mean x increased variance’ treatments (e.g. swap between mock panels/sprinklers -50% capture panels). Given the odds of 0.5, it is likely that a typical treatment flip will require ~10 plots (5 pairs) to be rotated; probably 1 day worth of work per site for a field crew. In the event of a “Technician’s despair” scenario, whereby all paired plots have been assigned a treatment flip (a 0.1% likelihood), an MVE site may require all 20 paired plots and their irrigation systems to be reassembled.

Originally, all MVE shelter panels were suspended at the bracket junctures via 6” carriage bolts inserted into the conduit. However, a new design was implemented in between the construction of MVB (1st site) and MVG (2nd site) for paired plots. This new vertical pin (detailed in next section) allows for much quicker and easier panel removal and installation. Given time all paired plot panels will be retrofitted with the vertical pin design, probably starting during the first official treatment swap at MVB in October 2020.

Photos and additional info can be added here.

Vertical pin design (December 2019)

The previous section alluded to the fact that a design change happened between the installations of MVB and MVG. The 'vertical pin' was incorporated into the design of all paired plots at MVG in hopes that it would add multiple benefits to the shelters such as wind abatement and facilitation of panel swapping described in the previous section. The vertical pin was only implemented on paired plots (20 plots per site) because installation takes a fair amount of time and is yet untested over long time periods; hence the unchanging plots at all sites have kept the carriage bolt design. The rest of this section is re-pasted from a 2019 document justifying and detailing the design. Some information may have changed over time, and the design itself may be subject to future unforeseen drawbacks. Still, it contains important information on the current shelter design.

Removing and swapping panels
12/19/19

Description:

Instead of using carriage bolts to hold up *both* ends of each conduit, a new method of attachment for the *outer* ends of the conduit is as follows. On the outer facing end of each conduit, a vertical hole in that conduit will be drilled so that it aligns with the corresponding but opposite hole in the angle iron (aka bracket) which formerly held the carriage bolt. A pin or fastened bolt (see bolt vs. pin section) will then be inserted downward through both the conduit and the bracket (figure 1). The conduit will then be bound to the bracket. Neither side to side nor up and down movement of the rainout panel would be possible except in cases of hardware failure (see issues debunked section).

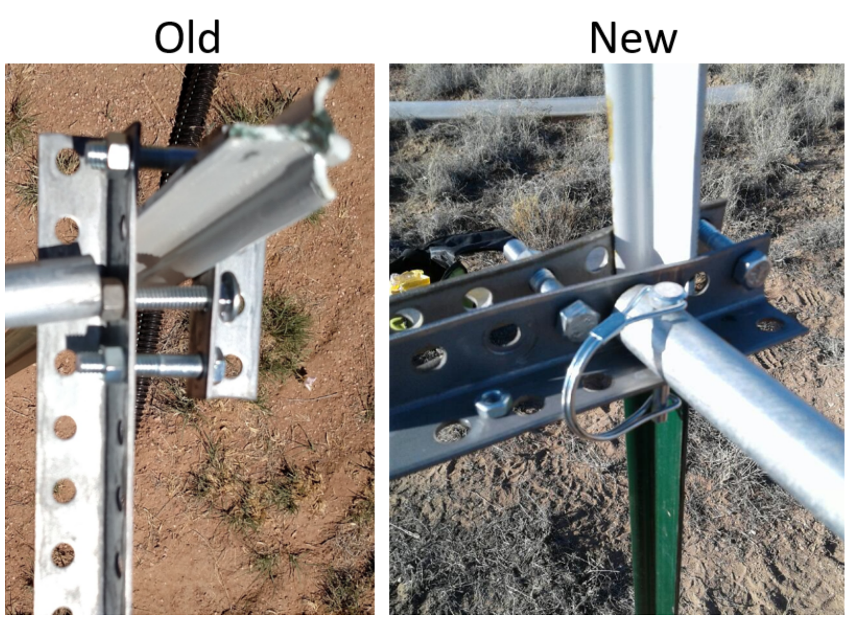


Figure 1: the vertical pin or bolt of the new design allows for quicker and easier removal while maintaining the same placement and fitting (e.g. the conduit still sits in the same position it would in the original design)

Why do this:

The MVE shelters require an annual rotation to achieve the effect of increased variance in precipitation.

Twenty plots, each with 4 rainout panels, are rotated with their respective paired plot. This means up to 80 panels must be removed and re-attached to achieve the MVE experimental design.

To remove and re-attach a panel using the current carriage bolt design is a tedious endeavor. Unscrewing the nut that binds the carriage bolt to the bracket can take several minutes and each panel has 2 to complete – a total of 160 carriage bolts to unwind.

Because of the often awkward way the panel applies pressure to the bolt and because of a lack of proper tools (carriage bolts were not meant to be unscrewed in this manner), several people can be required to assist each other in the task. Additionally, wear and tear on the hardware (e.g. bolts being shaven against posts/brackets as they rotate) as well as people's hands (again, heavy panels against small spaces make for sharp + awkward conditions) can result from this seemingly straightforward task. Figure 2 shows the current method of removing carriage bolts, where a wrench holds the nut in place while the technician unwinds the bolt in order to slide it out from the bracket and hence release the conduit.

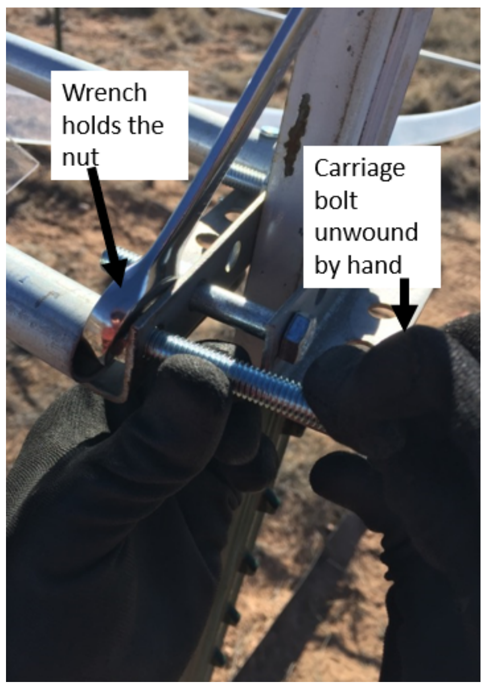


Figure 2: current way to remove rainout panels via carriage bolts

In addition to carriage bolt removals, a field day(s) at a site to complete this annual work comes with additional tasks. Carrying panels from plot to plot, loosening of shelter support wires, flipping the irrigation system, and general maintenance such as fixing broken panels and tightening brackets are all part of upkeeping the experiment. Being that there will be multiple Sev-MVE sites, completing all these tasks means a big investment of time which could be minimized by an improved design.

Finally, switching to this new design should save money in both labor-time and material. While the exact savings of this new method depends on the particular hardware used (bolt vs. pin), materials minimization occurs in two important ways. Carriage bolts would be reduced by 50%, and while a direct replacement occurs with the nut and bolt option – they would be considerably smaller in size and hence cost. Additional savings come from a 50% reduction in shelter U-bolts. There is no longer a need to avoid the 6” carriage bolt within the conduit, and so replacing the u-bolts (~ $1.50 ea.) is paid for even in the more expensive pin option (clevis pins are ~ $1.30 ea).

Bolt vs. pin; reasons why I recommend the pin:

The two hardware options for the respective bolt vs. pin types are pictured in figure 3. Both options accomplish the same function but come with several pros and cons. Of the options considered here, **both are cheaper than the current design, but I recommend using the pin**. Below I will detail three reasons why I like the pin.

Bolt Pin

Figure 3: bolt vs. pin option provides the same function but with slightly different considerations

--Price:

All items for initial field tests were purchased in town from True Value. The “clevis pin & clip” is a single item while the bolt requires a nut and ‘fender’ washer for tightening to the bracket (or a flange nut with no washer).

--1/4” x 2” carriage bolt ($0.33) + 1/4” nut ($0.19) + washer ($0.11) = **$100.80 for whole site**
--1/4” x 2” clevis pin ($1.29) => **$206.40 for whole site**

Note on the price: I did speak with True Value manager who said we could order our desired amount of 200 clevis pins and it is possible the price would drop even below his estimate of $1.29/pin.

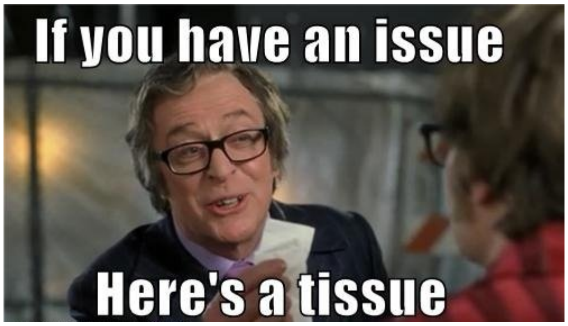
--Convenience:

While both options are very much easier to work with than the carriage bolt, the pin requires no tools nor the effort of tightening. While the strength of the pin is more questionable than a tightened bolt (see below) you would not have to worry about the pin loosening over time, whereas the nut and bolt could do so, possibly requiring maintenance checks either way.

--Longevity:

Finally I will talk about the most important issue: how it will hold up over time. A big concern is how the structures maintain integrity/functionality throughout the years and throughout many intense weather scenarios, which let’s be real means wind. The bolt can bind the conduit extremely tight to the bracket, which means shaking of the structure at the junction would be slim to none during wind. On the contrary, the pin is only as strong as its insert, which if damaged sufficiently could cause entire panels/shelters to fail. Nevertheless, shake tests were done to simulate severe winds (see issue debunked #5) and the results seem promising that the pin should maintain strength over time.

Issues debunked:



--Issue #1: Why not use 6” hex bolts (instead of carriage bolts) so you can use a drill to remove the outside bolt in seconds?

This was considered during the buildout of the first Sev-MVE site. However it became clear in searching for full threaded 6” hex bolts that the product was both rare and expensive. Finding a) the quantities we wanted and b) in prices comparable to carriage bolts was difficult online and in town. Recent options from an Amazon.com search on 12/19/19 showed no improvement: $0.60/carriage bolt when bought in a 50-pack vs. $1.60/full thread hex bolt when bought in an 8-pack.

While this hardware would improve the existing situation, it would present new challenges and retain old ones. While the Sev owns a drill, it would still introduce this new step while necessitating multiple drills and adapters to avoid holding up a crew during this limiting step. More importantly though, the necessity of having an additional person hold up the conduit while the first person drills (in order to avoid bolt wear and tear) does not seem practical.

--Issue #2: Won’t this create the need for resizing dimensions and spacing that was specific to the carriage bolt design?

The answer is no, even though the inevitable offset placement of T-posts will likely continue to create misfits and complications (issue #3 addresses this).

As seen in Fig 1, the placement of the vertical bolt positions the conduit in the exact configuration of the carriage bolt design. In three ways, this removes any need to resize dimensions or spacing of the plot grid and/or shingle spacing. **1)** Ideally*, the ends of the conduit should rest flush against the inside of the L-shaped bracket. This is achieved by the specific placement of the T-posts which accommodate the specific length of the conduit cuts. Ensuring the vertically drilled hole aligns the conduit up in this manner, no side-to-side misfits should occur. **2)** In that same vein, no front to back misfits (the lengths parallel to the shingles) should occur either since the conduit should be fastened to the same spot that the carriage bolt would otherwise be holding it. **3)** The aligned bracket hole and vertical pin occur <1” from the edge of the conduit, and the head of the pin sits flattened on top of the conduit. This means that the starting point for drilling shingle holes (5.5 cm or >2”) is unobstructed, and all spacing for subsequent holes can remain the same.

*We all know that the deal we were dealt does not delve into the depths of idealism. Discover what to do in the deft display that is divulged in issue #3.

--Issue #3: Why leave the carriage bolts on the inside?

It is possible that the vertical pin could be done on both ends of the conduit-bracket attachment. However, the design proposed here would leave the existing carriage bolt design for the insides. The main reason for this is to combat errors in distances that arise from misplaced T-posts. Specifically, if T-posts are placed too far apart from one another, then the vertical pin design would render it impossible to attach one or both conduits to the inner bracket. Thus, having the two 6" carriage bolts on the inside brackets provides a buffer that would make up for lost distance if all T-posts are not inserted perfectly (which can happen for a number of reasons – i.e. poor grid measurement, lateral movement during installation, crookedness etc.). Figure 4 is an example of this.

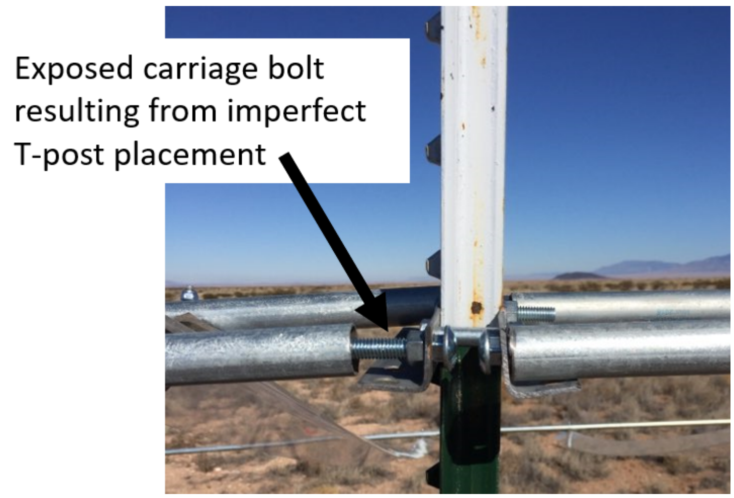


Figure 4: an example of the benefit of leaving carriage bolt design in the middle brackets to make up for imperfect distances that would stress vertical pins; eventually the T-posts are tightened and the conduit fits ideally, but only after panels are installed

Obviously, exposed carriage bolts indicate a problem and can lead to shelter failure on the inside portion of the rainout panels. For the three center T-posts this will be resolved by installing tension wires which pull together T-posts to the ideal position and provides rigidity to combat wind. On the lower end (which is not as susceptible to wind failure and hence warrants no expensive tension wires as of the date of this document), the vertical pin design may still provide structural improvements by limiting side to side movement which the carriage bolts did not.

Finally, it is worth noting that leaving the current carriage bolt design **only on the inside brackets** does not pose the same maintenance problems as the carriage bolts on the outer ends. After the outer carriage bolts are removed, two people are required to laterally slide the panel off the inner carriage bolts (having two people for this task is unavoidable even for the new design). This means no unwinding of the inner carriage bolts is required. As of the writing of this document, the sliding of panels both onto and off of the inner carriage bolt has not proven difficult.

--Issue #4: Holes drilled in the conduit for shingle attachment are not parallel with the up and down hole of the vertical pin. How will you know where to drill the vertical hole relative to the shingle holes?

From the high end to the low end of the rainout panels, there is a ~2 ft. difference in elevation. This means that the shingles attached to the conduit are slanted rather than vertical. In turn this means that the vertically drilled hole for the pin attachment will have to be offset at an angle relative to the shingle holes.

For the prototype of this design in December 2019, the vertical pin holes were all drilled in the field. This was a tedious endeavor that took several steps: setting and aligning the conduit onto the bracket and hole where it would be drilled; using a smaller drill bit for the pilot hole; drilling the final ¼" hole while the conduit sits precariously in the air. While doing these steps in the field was annoying it need only be done once for the panel. Further, it is possible that when a few panels are built and replicated, the angle of the vertical pin hole vs. the shingle attachment holes can be measured and we could incorporate it into the machine shop protocol for large scale buildout efforts.

--Issue #5: Will this design be as structurally sound as the original? Will the pin insert bend under windy conditions?

Only time will tell how the vertical pin will hold up in the wind and other inclement weather. However, the last section of this document details several brute-force tests (field test #2) that were administered on the initial prototype structure of the design which may give clues to the answer.

--Issue #6: How much will the new design cost?

As mentioned, the new design should actually provide costs savings in terms of material as well as labor hours in annual MVE maintenance. The following list highlights the estimated savings:

- A conservative time est. for unwinding a carriage bolt for 1 person (though awkward bolts may need a helping pair of hands) is 3 minutes (see field test section). This means it would take at least 8 hours to remove all 160 bolts for the shelter rotations at a site. If the pin can be removed in seconds, this creates much more time to complete the rest of the tasks that the rotation requires.
- Hardware prices:
  --3/8" x 6" carriage bolt ($0.60) + 3/8" nut ($0.12) + U-bolt ($1.49 @ Rak's) = **$353.60 whole site**
  --1/4" x 2" clevis pin ($1.29) => **$206.40 for whole site**

Field tests:

To test the feasibility of this design, we did a number of practical field tests. The construction crew hired to install the T-posts at the Black Grama site did the majority of their work the week before Christmas 2019, so we chose this site to create a mock shelter to confirm the T-post were being correctly inserted. The following tests were done at this site (MVE Black, Plot 1).

--Test #1: Time test for unwinding the carriage bolts

As discussed, unwinding of the carriage bolts in the current design (figure 2) is difficult and time consuming. This must be done up to 160 times (depending on the year) at each site during annual treatment swaps. This takes a very long time to accomplish just one aspect of the total field work required for the swap. We tested to see what an ***ideal*** amount of time for unwinding a single carriage