White Paper - Development and Engineering Aspects of the AZFS Moisture Level System

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Summary

The Moisture Level System was developed in 2004 by inventor Mr. Bob Brown to control expansive soil heave under concrete slabs. The system uses a variation of sub-slab depressurization to induce surficial drying in expansive clays under slabs. The development, design and multi-year testing results of the Moisture Level System are presented in this White Paper.

Background

Bob Brown is the Owner and President of Arizona Foundation Solutions (AZFS) and developer of the Moisture Level System (MLS). Brown has a Bachelor of Design Science degree in Housing and Urban Development (1984) from the School of Architecture and a Bachelor of Science in Finance degree from the School of Business (1984), both at Arizona State University. AZFS has performed over 8,000 house foundation investigations and stabilized or repaired more than 4,000 homes over the last 15 years. Brown has been working on the development of the MLS system for more than 15 years, has patented the procedure and has installed the MLS on over 1,000 home sites since 2014 to help reduce and control soil expansion under home slabs.

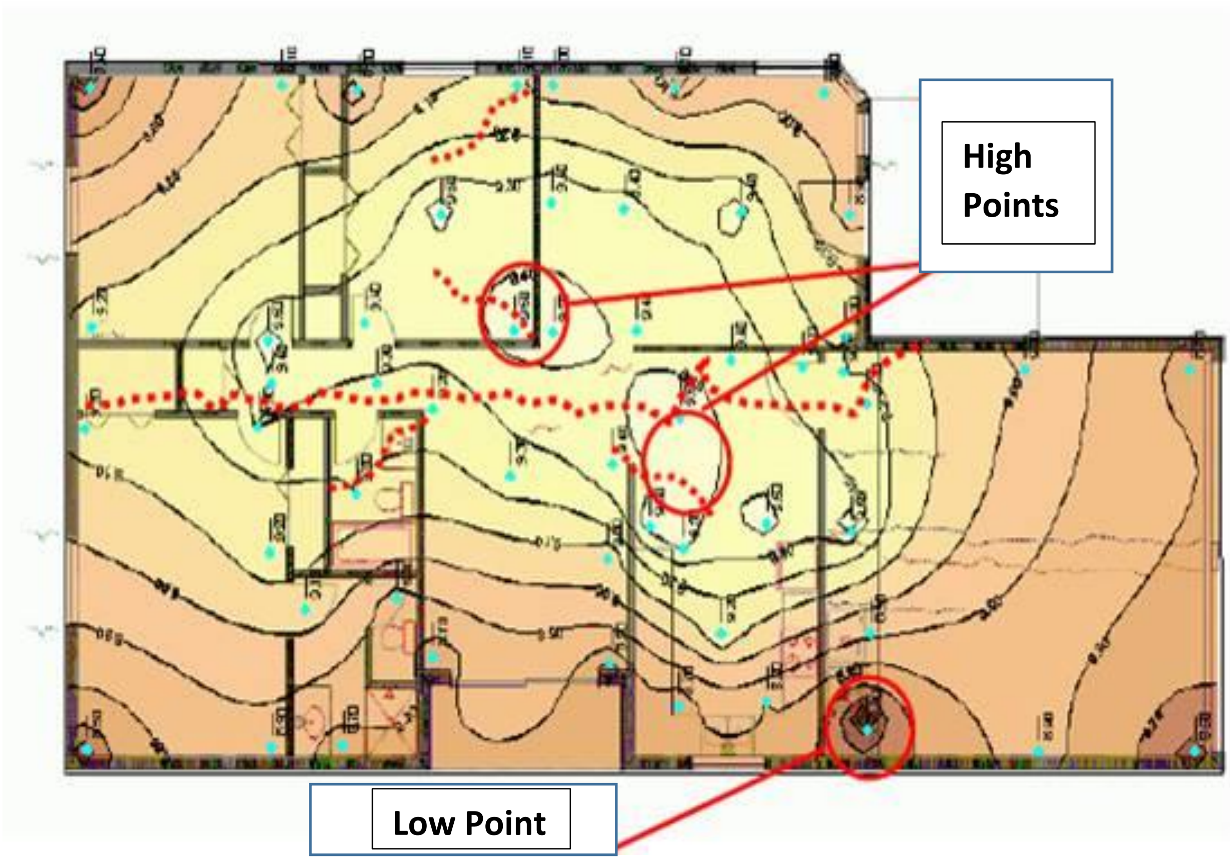
J. David Deatherage, P.E. is a senior geotechnical engineer and President of Copper State Engineering, Inc. Deatherage has a Bachelor of Science degree in Civil Engineering (1978) and a Master of Science degree in Civil Engineering (1980), both from Arizona State University. Deatherage has worked with geotechnical remediation alongside Brown for more than 15 years and provided technical support to Brown during the multi-year development of the MLS. While working on his Master’s Degree at Arizona State University in 1979, Deatherage developed a system of soil loading on model steel culverts that used pressurized air flowing through sand to simulate lateral earth pressures. It was found through both literature review and experimentation that a linear head loss of air pressure through the sand was experienced when the total air pressure head loss through the sand was a small percentage of the atmospheric exit pressure.

During the 1989-1995 time frame, Deatherage worked in the environmental industry remediating underground storage tank (UST) leaks. For volatile fuel leaks such as gasoline, vapor extraction wells were installed to depths of 5 to 100 feet and vacuum extraction blowers were used to draw air through the fuel impacted soils under the UST leaks. The volatile fuels were removed by evaporation into the venting air. Condensation traps in the venting system piping generated considerable volumes of water, particularly during times when the ambient air temperature was lower than the temperature of moist air discharged from the vapor extraction wells. Deatherage observed that vapor extraction wells dry out moist clay soils, with resultant shrinkage and settlements in the clay soils. In some cases there were many inches and even feet of settlement adjacent to vent wells and resultant tilting, separation and cracking of overlying structures. As part of the monitoring of these venting systems, relative humidity, temperature and air flow measurements were taken and it was possible to estimate the pounds of water removed each day by the vapor extraction wells. In 1990 Deatherage authored an article “Ground Settlements Induced by Soil Venting” in order to bring attention to potential settlement problems with soil venting in moist clay soils.

At the same time the EPA was publishing articles on sub-slab depressurization (SSD). SSD was described as the most common and most effective radon reduction strategy in basement and slab-on-grade houses. An SSD system consisted of one or more pipes attached to a fan or blower which creates a suction. Suction is measured with a digital micro-manometer with a 0 to 20-inch water column (WC) range and accuracy of +/- 1 percent. The pipes usually originate in a pit dug into the fill material underneath the concrete slab flooring of a house. Testing of SSD systems is conducted with vacuums of 2 and 5 inches of water. The literature warns against placing the pits near the perimeter of a home when there are expansive soils under the perimeter footings. The pipe is typically concealed in a closet corner or an unfinished area. Where possible, the piping is routed upward to the attic and vented though the roof (EPA, 1991).

In discussions in the early 2000’s, Mr. Brown noted that there was center “dome” heave in the concrete floor slabs in many of the homes in which he was performing foundation repairs. This dome heave was frequently misdiagnosed as perimeter settlement. Typically these homes were located in areas of near surface expansive clay soils in the greater Phoenix, Arizona area.

Floor level (manometer) surveys of relative interior slab elevations are commonly used in forensic geotechnical work to identify how much floor movement is present in homes. Manometer surveys are corrected for different flooring thickness over slabs and are accurate to +/- 0.1 inches. Comparing repeated manometer surveys is extremely valuable in monitoring ongoing slab movements. An example of dome heave is shown below.



Brown believed that an under floor slab air venting system could be used to reduce the accumulation of moisture in the expansive clay soils under the floor slabs. Brown reasoned that if the expansive clay soils under a slab could be dried with ambient low humidity air common to the Phoenix, Arizona warm and dry climate, the floor slab dome heaving movements could stop and possibly even reverse.

Deatherage noted that because the air flow through sand at low relative pressure gradients approximates the flow of an incompressible fluid, it was thought that it would be possible to draw air with low suction from wide areas under a home.

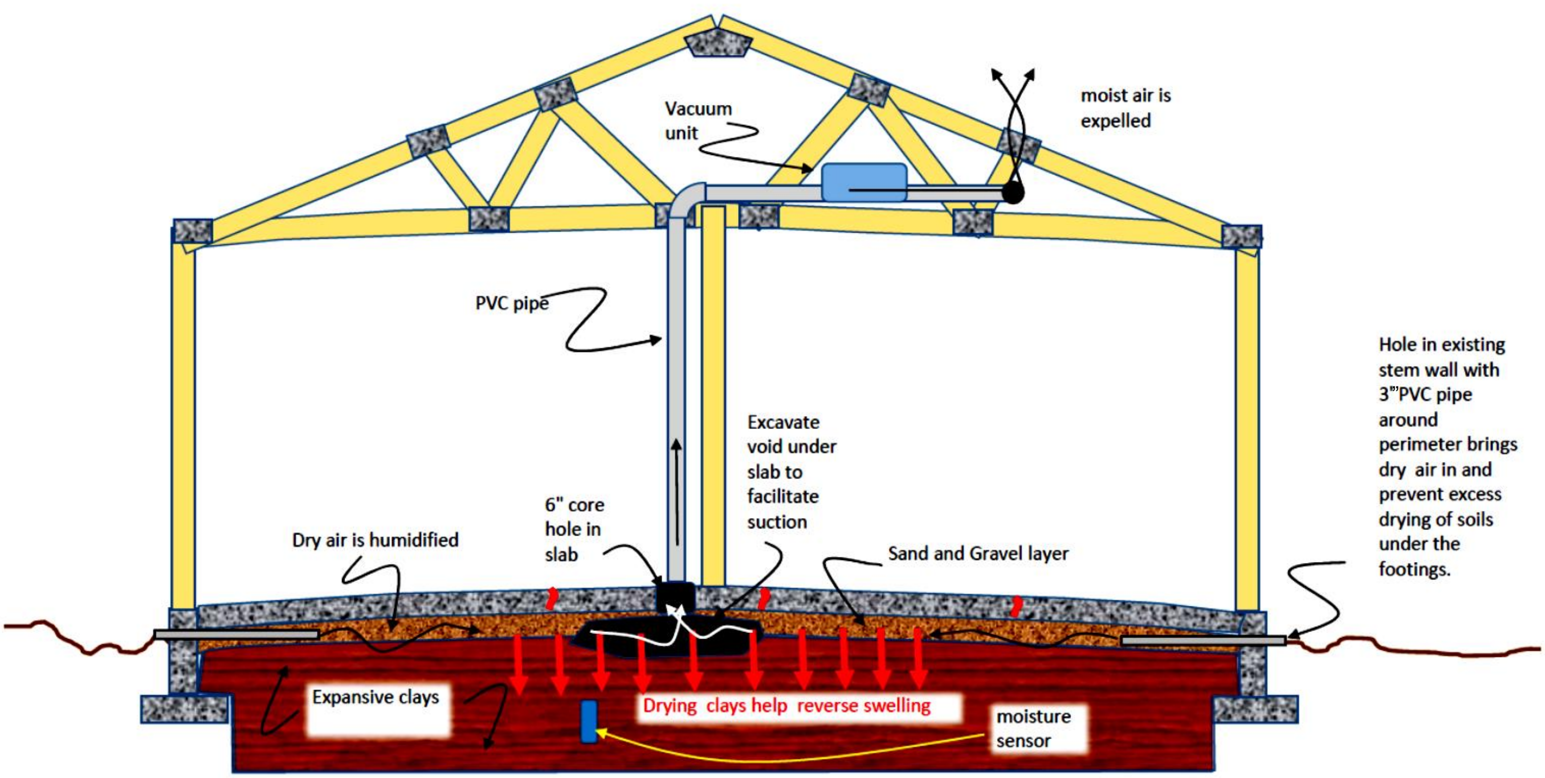
Conventional three pour footing and floor slab foundation systems in the greater Phoenix, Arizona area typically have four inches of aggregate base (AB) material first placed under the slab. In some cases fine gravel is also used. The MLS developed by Brown uses a low suction vacuum fan to extract air from the AB layer under the slab. Brown adds ambient air intake ports on the perimeter stemwall around the interior extraction point to encourage ambient low humidity air to flow through the AB to the extraction point.

Moisture Level System Components

Brown has since developed patented technical approaches to removing moist air from under concrete slabs and replacing with dryer air in order to better control heave of expansive soils under homes. AZFS has installed hundreds of these systems in Arizona with encouraging results to date.

The MLS in its current state of development includes the following components:

- Moist Air Extraction Pit (inside 6" diameter core hole through slab)
- Electric Low Moisture Cutoff Sensor
- System Exhaust Venting Piping (4-inch diameter PVC)
- Vacuum Fan (1-3 inch of water suction in-line fan). Fan is low noise and has low power consumption.
- Water Manometer Vacuum Measurement
- Perimeter Stem Wall Ambient Air Intakes
- Exhaust Pipe Outlet



Moisture Level System Monitoring

Monitoring of the MLS operation includes observation and/or measurement of:

- System suction measured in water manometer (inches of water)
- Exhaust pipe (4-inch diameter = 12.57 square inches) and average measured exhaust velocity (feet per second) measured with velocity meter.
- Exhaust air temperature (degrees Fahrenheit) and exhaust relative humidity (percent)
- Ambient air temperature (degrees Fahrenheit) and ambient relative humidity (percent)
- Ambient air intake ports suction (inches of water) measured with Digital Micro-Manometer.

Water Manometer and Digital Micro-Monometer used to Confirm Extent of Suction Under Slab

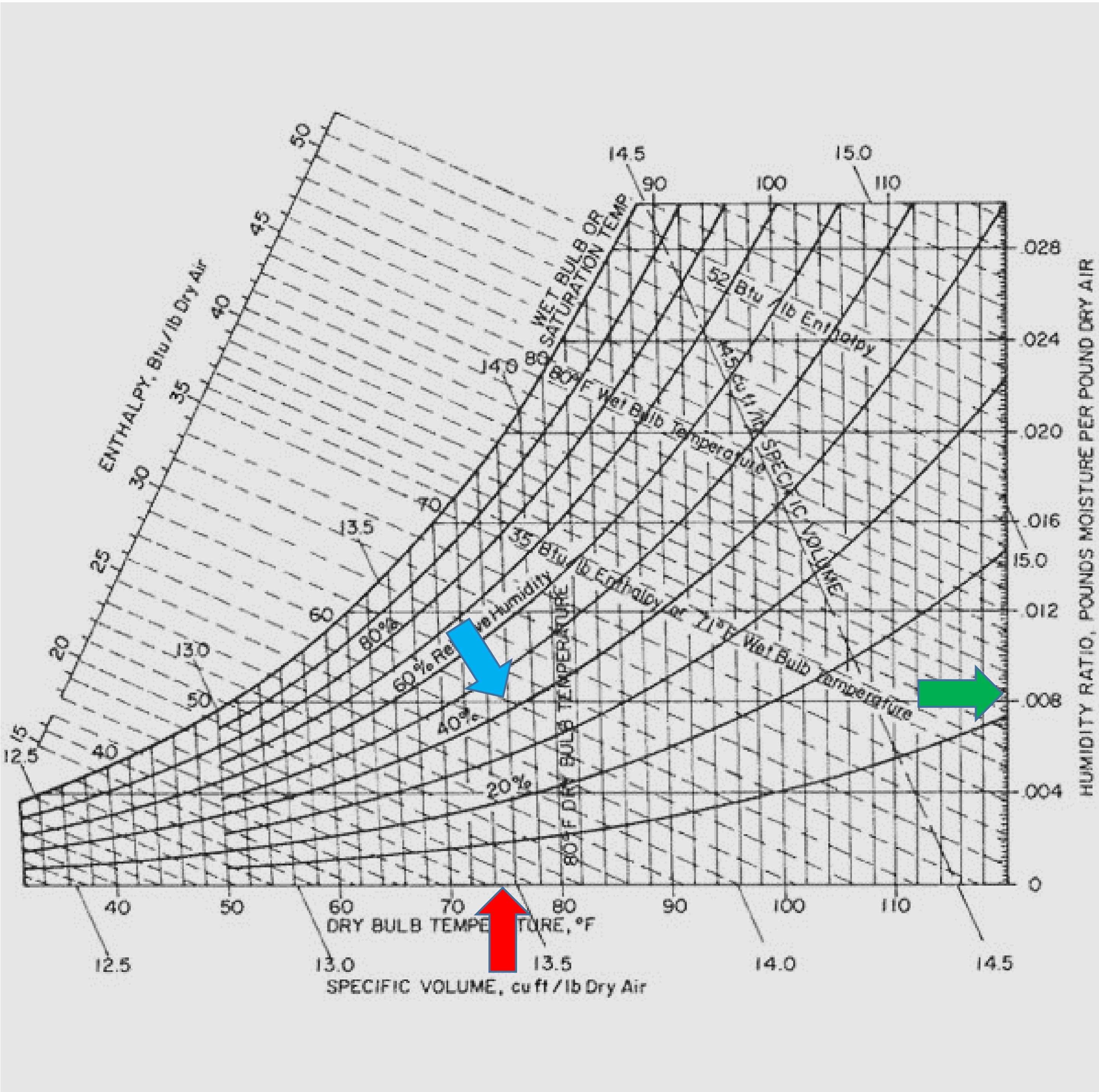
Measurement of Suction at Outside Air Inlet with Digital Micro-Manometer

Estimation of MLS Water Removal Rates

The discharge rate of the moist air from under a slab, the temperature and the relative humidity of the exhaust air, and the temperature and the relative humidity of the ambient perimeter inlet air can be compared to calculate the pounds of water removed each day by the MLS. From basic thermodynamics, one cubic foot of dry air at standard temperature and pressure (STP) 60 degrees F and 1 atmosphere, weighs approximately 0.081 pounds.

- 12.4 cubic feet of dry air at STP (elev. 0 feet, 60 degrees F) weighs 1.0 pound.
- 12.9 cubic feet of dry air in Phoenix AZ (elev. 1,100 feet, 60 degrees F) weighs 1.0 pound.
- 15.2 cubic feet of dry air in Flagstaff AZ (elev. 7,000 feet, 60 degrees F) weighs 1.0 pound.

The temperature and relative humidity relationship can be shown on the psychrometric chart presented below. From the psychrometric chart, if the MLS exhaust air temperature is 75 degrees F (red arrow) and the relative humidity of the exhaust air is 45 percent (blue arrow), there is 0.0086 pounds of water per pound of air exhausted (green arrow).



Reference: Haresh Khemani, Bright Hub Engineering.

To calculate the moisture removal effectiveness of the MLS at a specific time, the moisture being removed from under the home slab must be compared with the moisture in the ambient air returning under the slab through the air intake ports on the perimeter of the home. The difference in these two amounts is the effective moisture removal rate expressed in pounds of water per day.

In the general Phoenix area, one pound of dry air takes up 12.9 cubic feet. If the MLS air exhaust rate is 0.5 cubic feet per second (cfs), there is 0.5/12.9 = 0.039 pounds of air per second exhausted. From the example on the previous page, if there is 0.0086 pounds of water per pound of air discharged, 0.039 x 0.0086 = 0.0003354 pounds of water per second, or 0.020 pounds of water per minute, or 1.2 pounds of water per hour, or 29.0 pounds of water discharged from the MLS per day.

From the psychrometric chart, if the ambient outside air temperature is 75 degrees F and the relative humidity of the outside air is 25 percent, there is 0.005 pounds of water per pound of outside air. In the general Phoenix area, one pound of dry air takes up 12.9 cubic feet. If the replacement air inflow rate is 0.5 cfs, there is 0.5/12.9 = 0.039 pounds of ambient air per second flowing back under the slab. 0.039 x 0.005 = 0.000195 pounds of water per second, or 0.012 pounds of water per minute, or 0.7 pounds of water per hour, or 16.8 pounds of water per day returning back to the AB under the slab. The difference between 29.0 – 16.8 = 12.2 pounds is the net water removed from under the slab per day.

Note that there can be an elevation correction added to the psychrometric chart as the chart is only strictly correct at sea level. Because we are mainly interested in the relative difference in moisture level contents between the ambient air and the MLS exhaust air for MLS in the greater Phoenix area (elev. 1100), no elevation correction has been applied to the readings in this reporting.

When and Where the use of the MLS can be Considered

We recommend considering the use of the Moisture Level System when there is a near surface strata of originally dry expansive clay soil that has become wetted and is heaving with a dome manometer pattern under a portion of a floor slab inside a structure. The source of the excess moisture should be identified and eliminated as part of this mitigation. There should be an air permeable layer of AB or gravel between the floor slab and the expansive subgrade soils. For areas outside the greater Phoenix area, we recommend considering both the seasonal variations in temperature and relative humidity and the climatic regions as discussed in the next two sections to screen for possible candidate areas for MLS treatment.

Greater Phoenix Arizona Relative Humidity (RH) Variation

We reviewed RH measurements taken twice each day (at noon and at midnight) in 2018 at the Maricopa County Flood Control District weather station (Durango Complex – RH Gage No. 3302). This weather station located in central Phoenix (Durango Street and 27th Avenue) yielded the following RH variation by month data:

2018 Month	RH Min. (%)	RH Max. (%)	Both RH < 31% (Days)	Both RH < 51% (Days)	One RH > 50% (Days)	Both RH > 50% (Days)
January	5	89	6	25	4	2
February	10	97	11	21	4	3
March	5	68	22	28	2	1
April	4	35	28	30	0	0
May	5	33	30	31	0	0
June	10	68	27	30	0	1
July	9	80	12	26	5	0
August	11	84	10	26	5	0
September	9	97	18	28	1	1
October	21	97	1	14	10	7
November	8	100	5	18	8	4
December	19	98	0	5	21	5

For 170 days in 2018 the ambient RH range was (4% to 30%) for both noon and midnight readings. These days in 2018 when the MLS will typically work very well to remove moisture from under floor slabs are highlighted in yellow above.

For 256 days in 2018 the ambient RH range was less than 51% for both noon and midnight readings. These days in 2018 when the MLS will typically work very well to well to remove moisture from under floor slabs are highlighted in green above.

For 60 days in 2018 the ambient RH range was above 51% for just one of the noon and midnight readings. These days in 2018 when the MLS will typically work well to marginally well to remove moisture from under floor slabs are highlighted in gray above.

For 24 days in 2018 the ambient RH range was above 51% for both the noon and midnight readings. These days in 2018 when the MLS will typically not work well to remove moisture from under floor slabs are highlighted in blue above.

Note that in October of 2018 there was a record six inches of record rainfall during the month in parts of the greater Phoenix Area. The relative humidity data for this month reflects the record breaking moisture conditions in October of 2018.

We recommend doing a similar review for areas under consideration for MLS use.

Arid and Dry Climate Regions in the United States

The Thornthwaite Moisture Index (MI) for different climatic regions in the United States provides a good estimate of locations where the MLS will work effectively to remove moisture from under slabs in homes. “Arid” areas where the MI is less than -20 (white areas below) are excellent candidates for effective drying of moist clay soils under slabs for much of the year. “Dry” areas where the MI is between 0 and -20 (light shaded areas below) are good candidates for effective drying of moist clay soils under slabs for much of the year.

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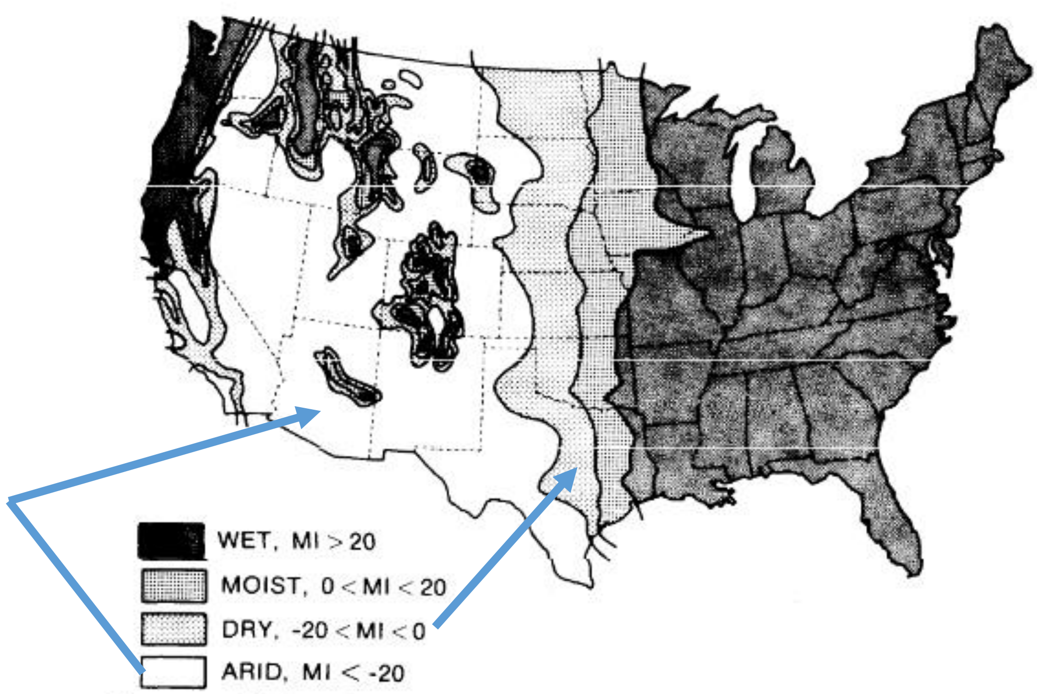


U. S. Army Corps of Engineers

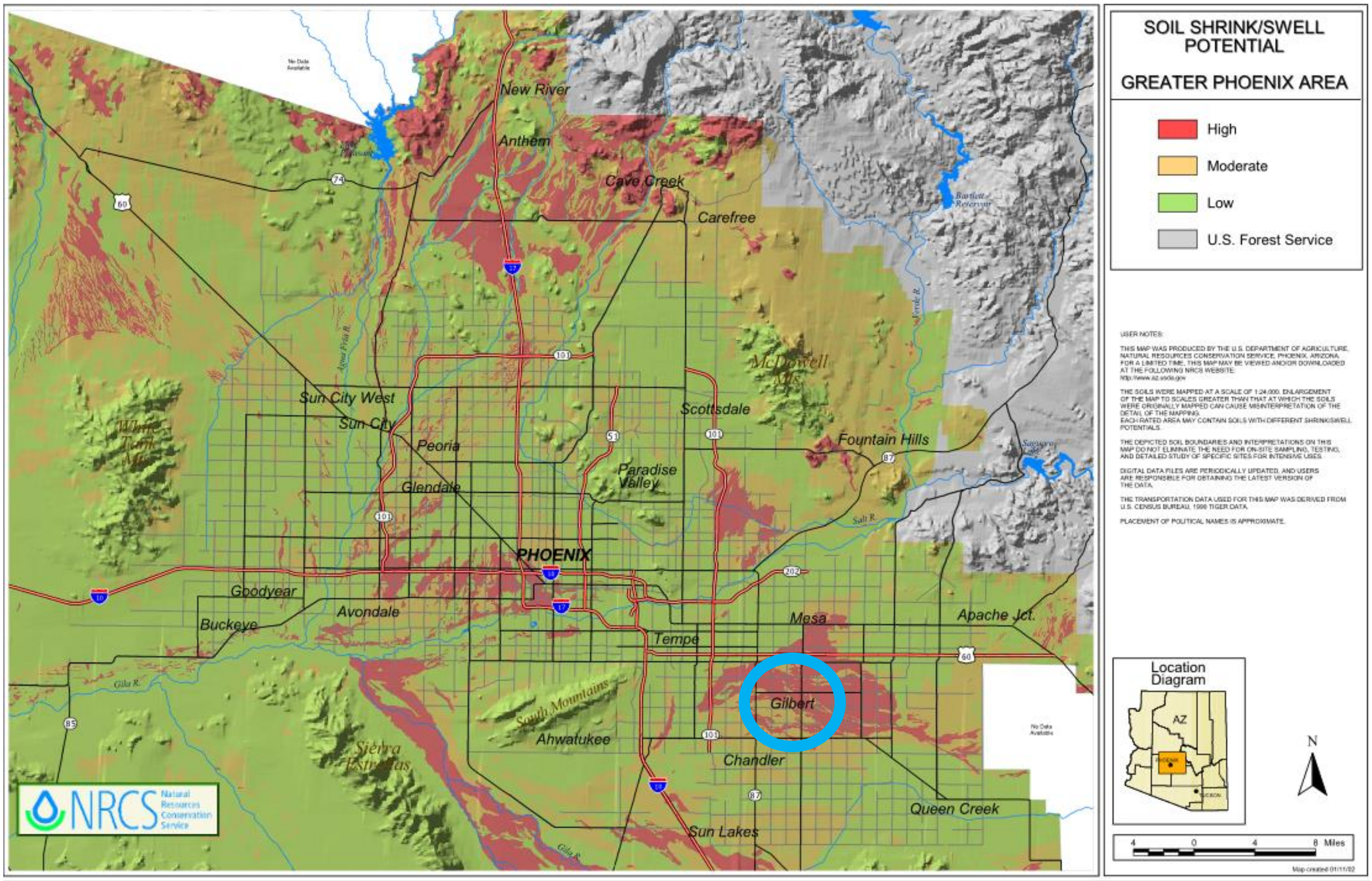
Figure 6–8. Approximate distribution of the Thornthwaite Moisture Index (MI) in the United States.

“Arid” and “Dry” candidate climatic areas in the contiguous United States for effective Moisture Level System during most of the year use include:

- Most of Arizona
- Most of Nevada
- Most of Utah
- Most of New Mexico
- Most of North Dakota
- Most of South Dakota
- Western 2/3 of Texas
- Western Nebraska
- Western Kansas
- Western Oklahoma
- Eastern Colorado
- Eastern Montana
- Southern California
- Portions of western Oregon
- Portions of southern Idaho
- Portions of Wyoming

Expansive Soil Areas in the Greater Phoenix Area

Mapped areas in the greater Phoenix area with “High Soil Shrink/Swell Potential” are shown in red below. This figure was published on 1-21-2000 by the National Resources Conservation Service (NRCS).



NRCS areas with “High Soil Shrink/Swell Potential” are considered candidates for the MLS when the expansive clays start out in a relatively dry condition under the home slab and then become wetted by any of a number of reasons. The blue circle above is an area in Gilbert Arizona where extensive near surface expansive clays are common.

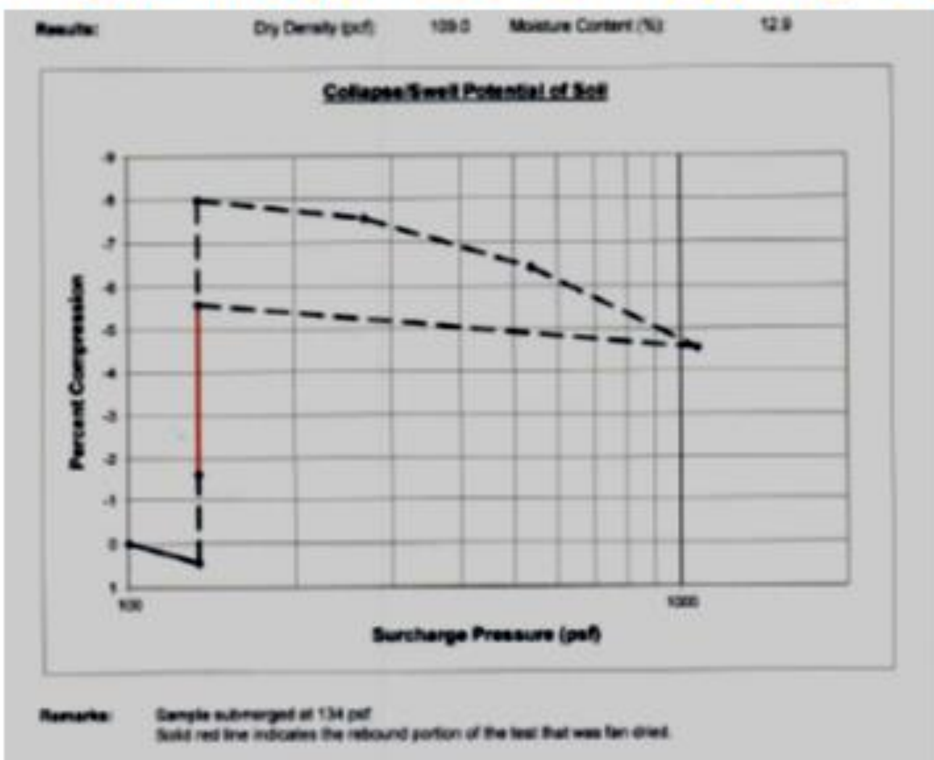
The NRCS has similar near surface soils information available for most regions in the contiguous United States, and we recommend characterizing each potential area of MLS use with similar near surface geotechnical information or with specific sampling and testing by a geotechnical engineer.

Suggested Geotechnical Testing

Suggested geotechnical testing to assess soil characteristics and to estimate how much heaved expansive clays can shrink back when air dried include both classifications tests: Particle Size and Atterberg Limits and a variation of the ASTM D4546-14 One-Dimensional Swell or Collapse of Soils (Response to Wetting) with added air drying at the end of the test.

In the response to wetting test shown below, an intact sample of expansive clay soil is first loaded to 135 pounds per square foot (psf) to simulate a typical loading of subgrade soils under a concrete slab. Then the sample is flooded with water and observed to swell 8.0 percent. Incremental additional loading of 270, 540 and 1080 psf are then applied and the soil compresses approximately 3.5 percent. Loading is then reduced to 135 psf and the sample rebounds (swells) approximately 1.0 percent. At this point the sample is then air dried with a small electric fan and the clay soil shrinks back an additional 4.0 percent. Clay soils with higher percent passing the 0.002 millimeter size and medium to high Plasticity Index will be more prone to exhibit the cyclic movement with moisture change exhibited in the testing below.

Example Response to Wetting Test



AZFS typically samples the soils removed from the extraction pit under the home slabs and has a particle size (down to the #200 sieve) and Atterberg limit Liquid and Plastic Limit tests run.

MLS Monitoring and Manometer Survey Results and Comments

AZFS has been monitoring the Phoenix area MLS installations for several years to date. The monitoring included comparisons of changes in floor level survey manometer readings and later the MLS moisture removal rate estimation.

Table A Results - Floor level manometer comparisons for MLS installations in the 2014 and 2015 time frame are shown as Table A, attached to this paper. Monitoring was performed from December of 2014 through November of 2015. Observations on this monitoring include:

- 24 sites with operational time of 3 to 11 months.
- Of the 24 sites, 12 show no slab elevation differences in the area of heaving.
- Of the 24 sites, 7 show lower slab elevations in the area of heaving, in a range of 0.1 to 0.5 inch, and an average of 0.26 inch.
- Of the 24 sites, 4 show higher slab elevations in the area of heaving, in a range of -0.1 to -0.2 inch, and an average of -0.125 inch.
- The average drop in elevation for all 24 sites was 0.054 inch.

Table B Results - Floor level manometer comparisons for MLS installations in the 2016 time frame are shown as Table B attached to this paper. Monitoring was performed between February and June of 2016. Observations on this monitoring include:

- 14 sites with operational time of 7 to 19 months.
- Of the 14 sites, 3 show no differences in slab elevations in the area of heaving.
- Of the 14 sites, 10 show lower slab elevations in the area of heaving, in a range of 0.1 to 0.3 inch, and an average of 0.14 inch.
- Of the 14 sites, 1 show 0.1 inch higher slab elevations in the area of previous heaving.
- The average drop in elevation for all 14 sites was 0.093 inch.

Table C Results – Additional 2016 floor level manometer comparisons with MLS moisture removal rate estimation are shown on Table C attached to this paper. Monitoring was performed during November 2015 through May of 2016. Observations on this monitoring include:

- 29 sites with operational time of 8 to 26 months, or in some cases not provided.
- Of the 29 sites, 18 have slab elevation comparison measurements.
- Of the 18 sites, 7 show no differences in slab elevations in the area of heaving.
- Of the 18 sites, 8 show lower slab elevations in the area of previous heaving, in a range of 0.1 to 0.5 inch, and an average of 0.21 inch.
- Of the 18 sites, 3 show 0.1 to 0.2 inch higher slab elevations in the area of heaving.
- The average drop in elevation for all 18 sites was 0.072 inch.

- Of the 29 sites, 26 have net MLS moisture removal rate estimates that varied from 0.1 to 105.5 pounds of water removed per day.
- The average net MLS moisture removal rate after 8 to 26 months of operation was 17.3 pounds of water per day.
- Of 27 sites with exhaust measurements, the average air flow was 0.49 cfs.

Table D Results – MLS moisture removal rate estimates are shown on Table D attached to this paper. Monitoring was performed during the initial operation of the MLS installed during January through July of 2019. Observations on this monitoring include:

- 62 sites with initial moisture removal estimates.
- The net MLS moisture removal rate varied from 5.0 to 238 pounds of water removed per day.
- The average initial installation net MLS moisture removal rate was 68.8 pounds of water per day.
- The suction measured on the MLS was noted for 56 of the 62 sites. The suction varied from 1 to 2.9 inches, with an average of 1.81 inches of water suction.
- The suction on the perimeter intake ports was also measured with at least some measurable suction in 42 of 46 measured ports.
- Of 62 sites with exhaust measurements, the average air flow was 1.05 cfs.

In 2019 AZFS returned to four of the original 2016 MLS installations. AZFS repeated the monitoring to see what variations would be encountered after almost three years of MLS operation. The locations of revisited sites numbered 2, 3, 7 and 8 are shown below.

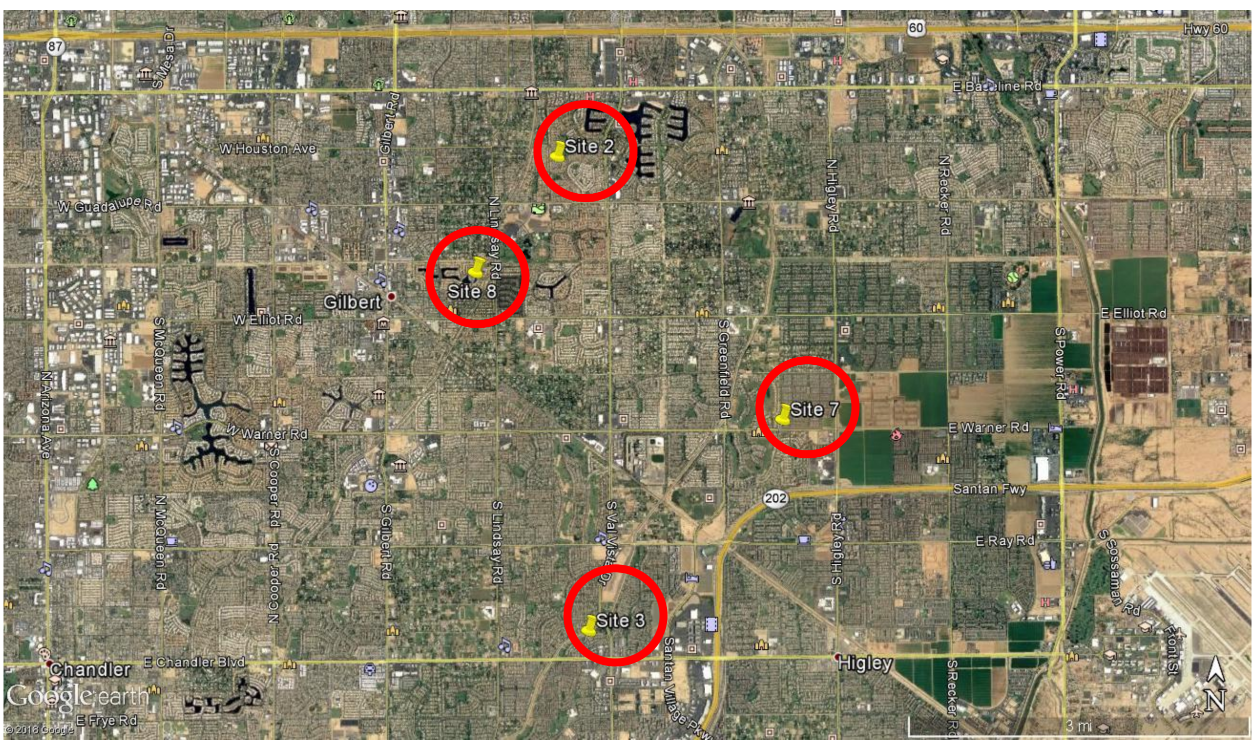


Table E Results – AZFS returned to four sites in Gilbert Arizona selected by Deatherage to check on next slab movements and net moisture removal rates after several years of MLS operation. The results of the manometer floor level changes and the moisture removal rate estimates are shown on Table E attached to this paper. Monitoring was performed during 2014 through 2019, with the last reading taken in March of 2019. Observations on this monitoring include:

- Four sites with operational time of 44 to 60 months.
- Two sites show no differences in slab elevations in the area of previous heaving.
- Two sites show lower slab elevations in the area of previous heaving, in a range of 0.3 to 0.7 inch, and an average of 0.5 inch.
- The average drop in elevation for all four sites was 0.25 inch.
- The net MLS moisture removal rate estimates for the four sites after 10 to 26 months of operation varied from 5.5 to 105.5 pounds of water removed per day.
- Of the four sites after 10 to 26 months the average air flow was 1.57 cfs.
- The average net MLS moisture removal rate after 10 to 26 months of operation was 48.5 pounds of water per day.
- The net MLS moisture removal rate estimates for the four sites after 44 to 60 months of operation varied from 0.0 to 62.7 pounds of water removed per day.
- Of the four sites after 44 to 60 months the average air flow was 1.43 cfs.
- The average net MLS moisture removal rate after 44 to 60 months of operation was 24.0 pounds of water per day.

Note:

The reported floor slab manometer elevation net differences are not necessarily the differences between the highest and lowest points. The heave is rarely so large that it encompasses the highest and lowest points. Also some areas have been poly-levelled and underpinned which may raise a low point. AZFS looks at the specific heaving area and measures how much elevation change happened just in the heaving area. In this way the variables mentioned above aren't impacting the MLS results (or are impacting as little as possible).

Suggested Areas of Additional Study

We recommend that additional work be done in the following directions:

- Continue returning to several dozen representative MLS installations that have been in place for several years and monitor floor slab elevation changes, MLS net moisture removal rates and perimeter intake suction.
- Characterize the effectiveness of the MLS for different AB materials and different thicknesses of AB layer.
- Characterize the effectiveness of the MLS for different subgrade soils by correlating geotechnical testing results with specific MLS installation sites.
- Try the MLS at higher elevations (5,000 to 7,000 feet) and in "dry" climatic areas.

- Check effectiveness in cooler winter weather regions such as Flagstaff, Arizona.
- Add a continuous reading RH sensor and have a system cutoff when the ambient RH is excessive, then restart the MLS when the RH drops back to a lower value. This RH sensor does not necessarily have to be added to each MLS if there is internet connection that allows the MLS to be turned on and off remotely when the humidity is high in the greater Phoenix area (or other climatic area).
- When the MLS moisture removal rate falls off, consider running only in dry periods.
- Return to sites with low air flow and/or low initial moisture removal rates and investigate the source of the problem.
- Test the MLS with higher suction fans for better results when needed.
- Experiment with opening and closing perimeter ambient air intake ports to reduce drying in some areas and increase drying in other areas.
- Test the MLS with Post-Tensioned slabs that exhibit dome heave.

Conclusions

The AZFS Moisture Level System is an effective alternative measure to mitigate expansive soil dome heave under lightly loaded residential concrete floor slabs that have a several-inch-thick layer of AB or gravel under the concrete floor. When used in climatic “arid” and “dry” areas with favorable relative humidity variations, the MLS can be effectively used to dry the surface of moist soils under concrete slabs during most times of the year. Depending on whether the subgrade soils are expansive clays that will shrink back when dried, or expansive clays that simply stop swelling when dried, the MLS can stop future clay heave, and in some cases cause the clay to shrink back and reduce the total dome heave. To prevent over-drying and possible excessive shrinkage of the expansive clay soils, AZFS incorporates an electric moisture cut off sensor buried approximately one foot under the AB that turns off the system when the expansive clay soils reach moisture contents under 8 to 10 percent.

As an example:

A one foot thick expansive clay layer under a 1,000 square feet portion of a concrete floor slab in Phoenix, AZ becomes wetted and heaves up two inches in a dome pattern under the floor. With a soil moisture content of 25 percent and a dry density of 105 pcf, there are 105,000 pounds of dry soil and 26,250 pounds of water in the one foot thick expansive clay layer. The MLS is installed with an average net moisture removal rate of 50 pounds of water per day in the first year of operation. It will take 262 days to remove ½ of the soil moisture from the expansive clay layer. Assuming the original moisture source has been eliminated, the expansive soil heave under the slab will be arrested as the clay soil dries out. Depending on the moisture variation cyclic nature of the expansive clay soil, the amount of heave may be actually reduced as the clay soil dries.

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Attachments

Table A	2014-2015 MLS Manometer Comparison Data for 25 Systems Running for Less Than One Year
Table B	2016 MLS Manometer Comparison Data for 14 Systems
Table C	2016 MLS Monitoring and Manometer Comparison Data for 29 Systems
Table D	New 2019 MLS Install Monitoring Data for 62 Systems
Table E	2019 Re-Read of Four MLS Sites in Gilbert Arizona with Repeat Manometers

Table A

2014-2015 MLS Manometer Comparison Data for 25 Systems Running for Less Than One Year

Customer ID.	Date of Re-Read	City	MLS Run Time (estimated) months	Elevation Variance (Before) inch	Elevation Variance (After) inch	Heave Reduction (inch)
1 SH	12/10/2014	Scottsdale	3	1.3	1.1	0
2 AL	11/18/2015	Surprise	6	0.8	0.8	0
3 HA	6/30/2015	Gilbert	9	2.1	1.8	0.3
4 MA	12/2/2015	Surprise	6	1.2	1.3	0
5 WI	12/2/2015	Surprise	6	0.9	1	-0.1
6 GO D	10/22/2015	Litchfield	8	2.4	1.5	0
7 GO G	6/20/2015	Gilbert	9	2.3	1.2	0.3
8 KN	12/1/2015	Mesa	7	2.7	2.1	0
9 KO	9/16/2015	Gilbert	6	0.9	0.9	0.2
10 LA	11/20/2015	Tempe	7	1.9	1.9	-0.1
11 CR	12/16/2014	Mesa	3	1.3	1.3	0
12 AN	11/20/2015	Phoenix	9	1.7	1.5	0.3
13 CA	4/29/2015	Mesa	5	1.3	1.4	0
14 FU	11/5/2015	Buckeye	8	1.9	1.9	0
15 GR	11/24/2015	Gilbert	6	2.2	2.2	0
16 GU	12/4/2015	Chandler	8	1.5	1.3	0
17 HA	5/14/2015	Casa Grande	7	1.2	1.1	0
18 HI	5/12/2015	Chandler	6	1.7	1.1	-0.2
19 HU	11/6/2015	Gilbert	11	1.3	1.3	0
20 MA R	12/4/2015	Phoenix	8	1.9	2.3	0.5
21 ME	12/7/2015	Peoria	8	1.6	1.1	0.1
22 MO	11/20/2015	Glendale	11	1	1.1	0.1
23 SO	11/23/2015	Surprise	1	0.9	0.9	0
24 ST	11/4/2015	Gilbert	10	1.9	1.6	-0.1

Table B

2016 MLS Manometer Comparison Data for 14 Systems

Customer ID.	Date of Sample	City	MLS Run Time (estimated) months	Elevation Variance (Before) inch	Elevation Variance (After) inch	Heave Reduction (inch) where + is shrinkage and – is heaving
ME	4/25/2016	Pinetop	11	1.5	1.2	0.3
TE	2/16/2016	Scottsdale	12	1.7	1.8	0.1
JO	5/25/2016	Gilbert	19	1.2	1	0.3
OB	6/3/2016	Gilbert	18	1.7	1.5	0.1
AN	6/8/2016	Gilbert	10	2.7	2.7	0
KL	3/15/2016	Pinetop	10	2.6	2	0.1
GI	6/8/2016	Flagstaff	7	1.5	1.5	0
NA	3/21/2016	Pinedale	8	3.3	2.9	0.1
NO	3/14/2016	Mesa	5	1.7	1.6	0.1
TE U	2/16/2016	Scottsdale	6	1.6	1.8	0.1
AP	5/10/2016	Tucson	10	2	2	0
TR	4/24/2016	Tucson		2.2	2.1	0.1
MO	4/28/2016	Tucson	7	0.9	0.9	0.1
CA	5/22/2016	Tucson	8	1.3	1.2	-0.1

Table C

2016 MLS Monitoring and Manometer Comparison Data for 29 Systems

(next page)

Customer Name	Date of Sample	City	MLS Run Time (estimated) months	Elevation Variance (Before) inch	Elevation Variance (After) inch	Net Heave Change (inch)	Estimated Exhaust Velocity (ft per sec)	Estimated Outlet Flow (cf/day)	Outlet Flow Air (pounds per day)	Temp. (Outside) F	RH % (Outside)	Pounds of water per pound of outside dry Air	Temp. (Outlet) F	RH % (Outlet)	Pounds of water per pound of outlet dry Air	Net pounds of water removed per day	Soil 12" under slab
DW	11/27/2015	Phoenix					1.6	12096	930	72.9	87	0.015	81.9	87.6	0.021	5.6	SC
YS	12/24/2015	Scottsdale					5.9	44604	3431	68	54	0.0085	74.5	50.6	0.0095	3.4	
HH	01//16/2016	Chandler					1.3	9828	756	61.9	28.1	0.003	79.2	49.7	0.011	6.0	
DW	10/15/2016	Peoria					2.6	19656	1512	61.6	31.4	0.004	68.5	36.8	0.006	3.0	
LA	1/15/2016	Scottsdale					1.6	12096	930	56.5	42.1	0.0045	64.2	52.8	0.007	2.3	CL-ML
TL	1/15/2016	Gilbert					5.9	44604	3431	66.7	23.9	0.003	67.9	37.8	0.006	10.3	
AM	1/19/2016	Phoenix					2.0	15120	1163	46.9	59.2	0.004	69.4	99.9	0.016	14.0	
JM	1/22/2016	Peoria					1.6	12096	930	69.3	13	0.002	74.4	64	0.0125	9.8	
AJ	3/9/2016	Gilbert	19	1.2	1	0.2 (lowered)	19	143640	11049	66.7	20.3	0.003	72	31	0.005	22.1	
GS	3/8/2016	Suprise					1.6	12096	930	76	21	0.004	75.2	33.3	0.006	1.9	
DA	2/29/2016	Suprise					0.33	2495	192	86.2	9	0.0025	101.5	18.5	0.007	0.9	SC
RH	2/26/2016	Gilbert	12				33	249480	19191	77.5	17.3	0.0035	76.1	43	0.009	105.5	
BB	4/5/2016	Mesa					23	173880	13375	93.8	5.7	0.002	82.1	40.5	0.009	93.6	
TA	4/25/2016	Gilbert	17	1.3	1.3	0.2 (Lowered)	7.9	59724	4594	78.8	6.6	0.001	80.2	32.8	0.008	32.2	SM
GR	4/26/2016	Gilbert	9	2.1	1.5	0.1 (Lowered)	13	98280	7560	71.2	14.4	0.002	85.5	33.4	0.009	52.9	ML
CR	4/27/2016	Litchfield	11	2	1.9	0.1 (Lowered)	0.33	2495	192	85	12.3	0.003	97	10.7/12.2	0.0045	0.3	SM
RO	4/29/2016	Chandler	12	1	0.6	0.2 (Lowered)	0.33	2495	192	93.1	13.9	0.005	94.9	29.3	0.01	1.0	SC-SM
WB	5/3/2016	Buckeye	12	1.5	1.6	0	1.6	12096	930	93.1	9.6	0.003	90.7	22.7/15.7	0.005	1.9	SC
RC	5/5/2016	Mesa	11	2	2.1	0.2 (Lowered)	0.33	2495	192	93.4/94.8	11.4/8.1	0.003	95.1/103.8	13.4/26.2	0.005	0.4	
BT	5/6/2016	Wittmann	11	2.9	3.3	0.5 (Lowered)	2.6	19656	1512	70.2	35.2	0.006	73	41.2	0.0075	2.3	
DR	5/6/2016	Phoenix	19	1.2	1.2	0	2.3	17388	1338	na	na	na	58.3	25.2	0.003	na	
JD	5/9/2016	Phoenix	11	2.5	2.4	0	na	na	na	99.3	29.7	0.0125	100.5	37.3	0.015	na	
JS	5/9/2016	Mesa	13	3.2	3.5	-0.2 (Increase)	0.5	3780	291	92.3	13.3	0.0045	94.8	28.3	0.01	1.6	
SB	5/10/2016	Gilbert	18	2	2.3	-0.1 (Increase)	2.3	17388	1338	80.3	18.3	0.004	92.8	36.9	0.012	10.7	
JT	5/12/2016	Chandler	12	2	1.8	0	na	na	na	100.5	4.0	0.002	106	5.6	0.002	na	
CC	5/13/2016	Gilbert	26	2.2	2.3	0	19	143640	11049	96.7	7.7	0.003	89.9	28.3	0.0085	60.8	
DA	5/18/2016	Mesa	8	1.1	1.1	0.2 (Lowered)	0.7	5292	407	81.3	34.8	0.008	82.8	46.8	0.0115	1.4	CL
HC	5/19/2016	Suprise	9	1.2	1.2	0	0.33	2495	192	88.7	14.8	0.0045	93.7	13.8	0.005	0.1	
DG	5/20/2016	Gilbert	10	1.5	1.6	0	1	7560	582	91.2	18.4	0.0055	98.8	38	0.015	5.5	

Table D

New 2019 MLS Install Monitoring Data for 62 Systems

(next two pages)

Date of Sample	2019 MLS Installation No.	Average Exhaust Velocity km/hour	Exhaust Velocity (ft/sec)	Estimated Outlet Flow (cf/day)	Outlet Flow Air (#/day)	Ambient Temp. (Outside) degrees F	Ambient RH % (Outside)	Pounds of water per pound of outside dry ambient Air	Exhaust Temp. (Outlet) degrees F	Exhaust RH % (Outlet)	Pounds of water per pound of outlet dry exhaust Air	Net pounds of water removed per day	Micro Digital Manometer	J tube inches
1/15/2019?	73427-KK	15	14	102953	7981	69.1	34.5	0.005	70.3	60.1	0.009	32	0.130	2
1/15/2019	73261-AC	5	5	34318	2660	70.7	33.4	0.005	74.2	58.4	0.010	13	0.500	2
1/16/2019	70100-SF	5	5	34318	2660	74.7	41.8	0.008	76.3	62.1	0.012	11	0.600	2
1/17/19?	73160-BT	5	5	34318	2660	73.7	35.4	0.006	76.1	70.1	0.013	19	na	0.5
1/25/2019	55521-JL	7	6	48045	3724	83.1	16.5	0.004	81.5	57.9	0.013	34	0.800	2
1/29/2019	JS	3	3	20591	1596	82.3	19.8	0.005	84.5	40.6	0.010	8	1.400	2
1/30/2019	73933-GL	9	8	61772	4789	64.7	21.3	0.003	66.2	54.2	0.007	19	0.800	2
2/1/2019	73509-PY	12	11	82363	6385	86.7	18.6	0.005	83.2	41.7	0.010	32	?	1.2
2/5/2019	CK	5	5	34318	2660	61.7	45.2	0.005	63.5	82.5	0.011	16	1.7	2
2/8/2019	74284-DD	6	5	41181	3192	72.4	26.7	0.004	76.4	80.1	0.015	35	1.2	2
2/11/2019	73418-SR	5	5	34318	2660	60.4	29.7	0.003	63.4	68.7	0.008	13	na	na
2/13/2019	73562-BF	20	18	137271	10641	73.3	28.1	0.005	74.7	50.4	0.009	43	2.1	2
3/6/2019	JR	20	18	137271	10641	81.7	20.4	0.004	83.3	48.7	0.012	85	0.9	2
3/7/2019	58702-RL	8	7	54908	4256	79.7	20.1	0.004	80.5	61.4	0.014	43	na	2
3/8/2019	73741-CP	4	4	27454	2128	68.3	28.4	0.004	71.1	63.4	0.011	15	na	2
3/12/2019	74754-TS	23	21	157862	12237	66.7	30	0.004	68.4	84.3	0.013	110	0.011	1
3/14/2019	74070-KM	12	11	82363	6385	71.9	20.1	0.003	73.6	68.7	0.013	64	0.01	2
3/15/2019	66719-SG	15	14	102953	7981	81.4	19.7	0.004	83.3	59.4	0.015	88	na	1.8
3/15/2019	74747-PS	8	7	54908	4256	77	16.9	0.003	79.2	65.9	0.015	51	0.001	2.3
3/19/2019	74087-SV	8	7	54908	4256	78.7	17.6	0.004	79.5	48.6	0.011	30	na	1.8
3/19/2019	74110-BM	7	6	48045	3724	76.4	23.7	0.004	78.3	61.1	0.013	34	na	2.2
3/20/2019	PS	11	10	75499	5853	80.7	21.4	0.004	82.4	53.6	0.012	47	na	1.5
3/21/2019	75617-CB	32	29	219634	17026	67	25	0.003	75.2	81.4	0.017	238	0.076	1
3/21/2019	CG	22	20	150998	11705	77.4	27.8	0.005	76.4	59.6	0.011	70	na	1.5
3/27/2019	74841-JM	20	18	137271	10641	77.2	22.2	0.004	79.3	53.4	0.012	85	na	1.8
3/28/2019	75164-KW	15	14	102953	7981	63.5	21.2	0.003	65.1	58.4	0.007	32	na	1.2
3/28/2019	74333-MD	3	3	20591	1596	78	14	0.003	89.4	51.4	0.015	19	na	na
4/1/2019	71505-AB	18	16	123544	9577	61	12	0.001	72.6	48.7	0.009	77	0.003	na
4/4/2019	52620-CM	20	18	137271	10641	82	17.1	0.004	80.4	63.8	0.014	106	0.04	2
4/5/2019	74417-JW	20	18	137271	10641	80	17	0.004	80.3	51.8	0.012	85	0.482	2.2
4/15/2019	75112-JY	13	12	89226	6917	81	32	0.007	83.4	68.4	0.017	69	na	2

Date of Sample	2019 MLS Installation No.	Average Exhaust Velocity km/hour	Exhaust Velocity (ft/sec)	Estimated Outlet Flow (cf/day)	Outlet Flow Air (#/day)	Ambient Temp. (Outside) degrees F	Ambient RH % (Outside)	Pounds of water per pound of outside dry ambient Air	Exhaust Temp. (Outlet) degrees F	Exhaust RH % (Outlet)	Pounds of water per pound of outlet dry exhaust Air	Net pounds of water removed per day	Micro Digital Manometer	J tube inches
4/17/2019	74344-DH	7	6	48045	3724	76.9	36.8	0.007	78.5	68.7	0.015	30	na	2
4/19/2019	73882-JV	6	5	41181	3192	91.4	14.3	0.004	94.2	71.4	0.025	67	na	2.2
4/19/2019	75258-MR	1	1	6864	532	97	5	0.002	109	27.4	0.014	6	0.001	2.5
4/20/2019	73651-MC	34	31	233361	18090	85	12	0.003	93.1	45.3	0.015	217	0.14	2
4/22/2019	76150-KF	4	4	27454	2128	82.7	13.5	0.003	84.1	59.4	0.015	26	0.35	2
4/22/2019	75056-GF	37	34	253951	19686	86	12	0.003	82.4	62.3	0.014	217	0.023	1
4/23/2019	75423-MC	18	16	123544	9577	83	16	0.004	92.3	25.2	0.008	38	0.001	2
5/1/2019	75468-BW	17	15	116680	9045	78	28	0.006	84.9	71.4	0.019	118	0.113	1
5/2/2019	75256-AB	1	1	6864	532	86	13	0.003	102.3	38.5	0.016	7	0	2.25
5/6/2019	73292-CD	17	15	116680	9045	76.7	39.4	0.008	78.3	69.9	0.016	72	0.017	2
5/8/2019	74430-LS	16	15	109817	8513	81.7	28.9	0.006	85.2	79.1	0.020	119	0.8	na
5/10/2019	75388-BP	2	2	13727	1064	84	22	0.006	109.3	31	0.017	12	0	2.1
5/13/2019	74976-JB	27	25	185316	14366	89	24	0.007	80	62	0.013	86	0.88	1
5/13/2019	75615-BE	7	6	48045	3724	84.7	27.6	0.007	86.9	52.3	0.014	26	9.6	2
5/14/2019	70271-LO	30	27	205906	15962	97	14	0.005	89.5	58.4	0.018	208	0.053	1
5/15/2019	75569-ND	20	18	137271	10641	88.6	15.3	0.004	87.1	72	0.020	170	4.7	1.8
5/16/2019	75989-SJ	13	12	89226	6917	93	9	0.003	88.7	31	0.009	42	0.049	2
5/31/2019	72100-LD	13	12	89226	6917	77.3	15.4	0.003	79.1	65.4	0.014	76	6.8	1.8
5/31/2019	50640-DH	1	1	6864	532	95	6	0.001	92.4	37.4	0.011	5	0	na
6/17/2019	76469-CD	25	23	171589	13301	99	12	0.005	86.8	58.3	0.015	133	0.347	1
6/18/2019	76057-LB	16	15	109817	8513	98	8	0.003	98.4	47.6	0.019	136	0	1.9
6/24/2019	76973-GL	14	13	96090	7449	102	6.5	0.002	97	67.9	0.025	171	6.7	1.2
6/27/2019	77524-SS	3	3	20591	1596	100.1	7.1	0.002	101.5	52.7	0.023	34	0.9	2
6/27/2019	76093-JF	18	16	123544	9577	105	9	0.004	94.6	23.4	0.008	38	0.233	2
7/1/2019	73368-GR	39	36	267678	20750	108	12	0.006	99.3	42	0.017	228	0.043	0.001
7/2/2019	75533-DB	7	6	48045	3724	108.2	9.2	0.005	106.8	28.7	0.014	34	1.6	2
7/3/2019	76388-SM	7	6	48045	3724	105	11	0.005	90.1	68	0.021	60	0.014	2.1
7/5/2019	76407-RS	13	12	89226	6917	93	14	0.004	88	67.4	0.020	111	0.005	1.6
7/9/2019	77695-NS	17	15	116680	9045	104	4.2	0.002	102.1	23.2	0.010	72	0.8	2.9
7/10/2019	77132-GF	4	4	27454	2128	103	13	0.006	101.4	44.9	0.019	28	0	2.2
7/12/2019	76619-MC	15	14	102953	7981	108.6	10.3	0.005	119.7	23.4	0.012	56	1.4	2

Table E

2019 Re-Read of Four MLS Sites in Gilbert Arizona with Repeat Manometers

(next page)

Customer Name	Date of Sample	City	MLS Run Time (estimated) months	Elevation Variance (Before) inch	Elevation Variance (After) inch	Net Heave Change (inch)	Estimated Exhaust Velocity (ft per sec)	Estimated Outlet Flow (cf/day)	Outlet Flow Air (pounds per day)	Temp. (Outside) F	RH % (Outside)	Pounds of water per pound of outside dry Air	Temp. (Outlet) F	RH % (Outlet)	Pounds of water per pound of outlet dry Air	Net pounds of water removed per day
AJ	9/9/2014+/-	Gilbert		1.2												
AJ	5/26/2016	"	21	1.2	1.0	0.2	19	143640	11049	66.7	20.3	0.003	72.0	31.0	0.005	22.1
AJ	3/20/2019	"	54	1.2	1.2	0.0	18	137592	10584	88.4	17.5	0.005	78.8	22.1	0.005	0.0
RH	9/30/2014+/-	Gilbert		2.1												
RH	6/30/2015	"	9	2.1	1.8	0.3										
RH	2/26/2016	"	17	2.1			33	249480	19191	77.5	17.3	0.0035	76.1	43.0	0.009	105.5
RH	3/7/2019	"	53	2.1	1.8	0.3	31	232848	17911	78.8	12.4	0.003	81.4	29.1	0.0065	62.7
CC	3/3/2014+/-	Gilbert		2.2												
CC	5/13/2016	"	26	2.2			19	143640	11049	96.7	7.7	0.003	89.9	28.3	0.0085	60.8
CC	3/28/2018	"	48	2.2	1.5	0.7										
CC	3/18/2019	"	60	2.2	1.5	0.7	10	77414	5955	92	13.2	0.0045	87.4	27.8	0.0075	17.9
DG	8/20/2015+/-	Gilbert		1.5												
DG	5/20/2016	"	10	1.5	1.6	-0.1	1.0	7560	582	91.2	18.4	0.0055	98.8	38.0	0.015	5.5
DG	3/8/2019	"	44	1.5	1.5	0.0	6.6	49669	3821	68.7	19.9	0.003	69.5	42.7	0.007	15.3