CONSTRUCTION, CALIBRATION AND OPERATION OF A MONOLITH WEIGHING LYSIMETER*

by

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ABSTRACT

Construction of a hydraulic monolith weighing lysimeter was undertaken, however, due to inherent design and/or construction errors this proved to be an inadequate device for the accurate determination of evapotranspiration from Larrea divaricatta (creosote bush).

Prior inability to stabilize the lysimeter with respect to barometric and temperature fluctuations, and eventual failure within the hydraulic transducer package led to the eventual abandonment of the hydraulic load cell design, and adoption of an electronic strain gage transducer package.

This paper deals with the detailed design and construction phases of the original lysimeter, the inherent difficulties encountered, and with the modification and conversion of the lysimeter to the electronic transducer assembly. Accompanying test data with respect to sensitivity, response time and differential loading characteristics support the premise that the electronic load cell design has inherent maintenance and operational advantages over the hydraulic transducer lysimeter.

INTRODUCTION

Evapotranspiration losses have become an ever-increasing problem to the various water management and use agencies within arid and semi-arid regions. Extensive research projects to determine ET losses from indigenous vegetation have been undertaken in the Southwestern regions of the U.S., notably in Arizona, New Mexico and Southern California. The result of such research has met with more or less success depending on the case and methods employed.

Determination of ET losses for a large area involves two major divisions: (1) evaluation of ET of specific vegetative types, and (2) computation of total ET losses based on the density of cover over an area by vegetative types. Recent refinement of remote sensing techniques has greatly facilitated density estimates, however, accurate and reliable measurement of actual ET from specific vegetated plots has proven to be a problem (Abd El Raham, 1965).

The monolith lysimeter appears to be the only reliable, direct method of ET data acquisition. Other techniques being employed to estimate ET require a standardization source with which to compare over the range of interest (Garstka, 1974). As a great deal of valuable research of this nature is being conducted within the southwestern regions, it was felt that the construction of a monolith weighing lysimeter would contribute greatly toward the direct determination of precise ET rates, and in the interpretation of existing and future research results employing indirect techniques of measurement.

Through analysis of soil topographic maps and aerial photographs, several suitable site locations for construction of the lysimeter were located. Further ground level inspections narrowed the number of sites to two on the bases of their soil type, nearness to existing hydrologic and storage installations, and proximity to electrical power facilities. Test holes were dug with a backhoe in the vicinity of the sites to determine soil stratification and the presence of rocky and/or consolidated material. Mechanical soil sample analyses yielded an average composition of 79.5% sand, 10.4% silt and 10.2% clay by volume. On these bases, the present site was selected within the IBP Silverbell validation range located approximately 19 miles west-northwest of Marana, Arizona.

Selection of a representative creosote bush within the site was on the bases of its size, shape, condition and relative proximity to neighboring shrubs, since adequate distance (min. 3 meters) was required during the construction phase for heavy equipment operation.

Original design of the lysimeter was taken from that of Hanks and Shawcroft (1965) as modified by Fritschen et al. (1972). Further modification of Fritschen's design was required to suit a creosote bush and to meet the surface runoff measurement requirements.

With the aid of a local steel fabricating company components for the lysimeter were designed and manufactured. The lysimeter basically consists of four major components: an inner shell, an outer shell, a bottom floor plate, and a transducer assembly (originally this was a hydraulic assembly and later converted to an electronic strain gage assembly). The inner and outer shells were each fabricated from 12 gauge steel as two halves of a right cylinder (1 meter deep x 4 meters in diameter) which could be bolted together and later welded in the field. This was necessitated by transportation difficulties which would have been encountered in attempting to deliver two cylinders each over four meters in

*Research funds provided by International Biological Program (IBP) Grant No. 624 to the Department of Hydrology & Water Resources, University of Arizona, Tucson, 85721.

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diameter to the job site. For similar and construction reasons, the bottom floor plate was fabricated in the shop in sections 4.6 m long x 30.1 cm wide (15 ft long x 1 ft wide) by welding 4.6 m long x 15 cm wide x 5 cm deep, 4.8 mm thick (15 ft x 6" x 2", 3/16") tubular steel planks edge to edge. Continuous weld was used on one side and 1" on 12" weld on the other. Solid bar stock steel 20.3 cm wide x 5 cm deep (8" x 2") was used for the leading and trailing ends of the floor plate to give greater strength in the weld between the inner shell and the plate for emergency lifting purposes.

This yielded thirteen sections of bottom floor plate which would be installed one by one under the lysimeter. The leading edge of the solid stock was outfitted with a cutting wedge of 6.35 mm (1/4") steel set at a 50° angle to facilitate pushing through the soil column. Also, a water cock was fitted to one end of the cutting wedge and holes cut in the cutting face to aid in the process.

A transducer supporting plate, also fabricated in two sections, and the instrument well top cover together with the previously mentioned items were delivered on site on April 29, 1974.

The University contracted with a local construction firm for the actual installation of the lysimeter and excavation began on May 2, 1974. The two halves of the inner shell were set around the selected creosote bush on the soil surface and bolted together. After excavation of a trench 1.5 meters deep x 0.6 meter wide (5' deep x 2' wide) around the outside of the inner cylinder using a backhoe, the soil column was shaved to allow the shell to slide down around it. The inner shell was carefully leveled and blocked in place. It had been surmised that a soil column of 4 meters in diameter by 1 meter deep would contain approximately 95%$^+$ of the plants root structure (Cannon, 1870). This appears to be substantiated since only fine root hairs were encountered while shaving the soil column. Work done in the adjacent vicinity by Dr. John Thames (1972) of the Department of Watershed Management, University of Arizona, showed that creosote depth rarely penetrated below one meter in depth.

Further excavation on one side of the plot was accomplished to yield a construction pit approximately 4.5 meters x 6 meters (15' x 20'). This area would later be used to bury the instrument well.

After careful setting and alligning the bottom I-beams along the sides of the trench, and building the necessary cribbing to support the custom made 36 ton hydraulic jacks, we were ready to embark upon what became the most difficult of all the phases of the project -- <u>installation of the bottom floor plate</u>.

Two bottom planks at a time were laid edge to edge on the supporting I-beams and field welded to form a plate 4.6 meters long x 60.1 cm wide x 5 cm deep (15' x 2' x 2"). The first section contained the cutting wedge which was placed beveled edge up and was forced between the I-beams and the bottom of the inner cylinder under hydraulic pressure by the two 36 ton jacks blocked against the back of the trench bank. Each subsequent plank was welded and placed behind the previous one and likewise jacked forward.

Due to misallignment and shifting of the cribbing supporting the jacks and unequal hydraulic pressures and various other maladies, we were able to gain only about two centimeters per day on the advance of the floor planks under the inner shell. This process continued on through the summer months until July when about 4/5 of the way under the lysimeter a consolidated rock strata, heretofore undiscovered, was encountered. We were unable to wash away the restrictive formation with the water induction system built into the cutting edge, nor were we able to push the plate forward with the jacks as we had maximized the hydraulic pressure system and blown seals on the jacks on several occasions. It became obvious very quickly that a new tack was required.

Fritschen (1972) had met with similar difficulties in encountering boulders up to 0.9 meter in diameter and 1.5 meters in length by undermining the soil column and removing the rocks. The nature of the material encountered on our project ruled out undermining since, 1) the strata was consolidated which would have inhibited breaking up into manageable size chunks, and 2) we feared removal of the strata would cause a collapse of the soil column above.

The only recourse appeared to be to pull the inner shell, the remaining 56 cm (22") onto the bottom plate. In doing so, friction would be greatly reduced since the jacks would have to overcome only the resistance of the cylinder and soil column sliding over the top of the plate rather than the resistance of the plate moving through the soil column. By reversing the jacks and attaching them to a steel cable around the inner cylinder this was accomplished with a minimum of soil column disturbance.

Once we had the inner cylinder onto the floor plate they were welded together along the bottom periphery of the inner shell in a continuous water tight weld. Before welding could be accomplished, however, the inner cylinder had to be returned to a cylindrical configuration since stresses set up during installation of the bottom floor plate had warped the shell out of round by as much as 25 cm (10") at points of maximum deflection. To accomplish this approximately 25 centimeters (10") of soil was removed by hand from around the periphery of the inner cylinder, the shell manipulated back into a cylindrical shape (plus or minus one inch -- at points of maximum deflection) by means of mechanical "come-alongs", and finally, repacked with native soil to give a continuous and consistent soil column throughout. The supporting I-beams were tack-welded to the outer edges of the floor plate and 25 ton jacks placed on each corner. The inner cylinder, now containing the entire soil column and the floor plate, was then carefully jacked vertically approximately one meter in progressive stages while 10 cm x 15 cm (4" x 6") hardwood cribbing was placed underneath the outer corners.

As mentioned previously, our original design called for a hydraulic transducer package to be installed under the lysimeter. This was subsequently accomplished, however, it became immediately evident that certain inherent designed problems existed within the hydraulic transducer package, and in the manifold and manometer measuring systems. At first it was believed that the problem was entirely a matter of effects due to extreme temperature fluctuations experienced in the desert biome. Numerous steps were taken in an attempt to dampen out the temperature effects we were experiencing, however, we were still left with a cyclic (sine wave) diurnal output tracing which we were unable to explain. We now feel that the diurnal fluctuations we were recording coincide, in fact, with the normal diurnal sine wave tracings of barometric pressure.

Many months were spent toward correcting this problem, however, nothing appeared to alleviate the diurnal tracings we were receiving off the HP 7155A recorder. Due to the extreme sensitivity of the hydraulic transducers we have estimated that even a very small amount of air, which probably came out of solution upon temperature stabilization of the tubes, could have been responsible for the changes in head due to changes in local barometric pressure.

During an attempt to increase head in the transducer unit we experienced a blow out in one of the internal tubes, which caused a back siphonage from the remaining tubes through the connecting manifold. The lysimeter dropped and bottomed out on the transducer support plate, necessitating having to pick up the lysimeter for repairs to be made.

Several months previous we had been in contact with Transducers, Inc., a California based electronic strain gage manufacturing firm, over the possibility of using such devices for future application if another lysimeter was to be built. Based on the information furnished by them it was felt that electronic strain gage transducers were a feasible alternative to the hydraulic system. Since our existing lysimeter had to be pulled and the transducer package replaced anyway, it was decided to go ahead and install the electronic transducers under the lysimeter rather than merely replacing the somewhat questionable hydraulic package.

Since several other design modifications were desirable (i.e., additional access ports), and it was questionable whether the 28 ton lysimeter could be successfully lifted by a crane out of the hole, it was decided to dig up the entire outer cylinder to gain access to the lysimeter so it could be hydraulically jacked up the required distance, much as had been done during the initial construction phase. Through the use of a backhoe the outer cylinder was removed and access gained to the inner shell. By means of hydraulic jacks the lysimeter was rainsed approximately 56 cm (22"), the butyl transducers and transducer support plate removed, and forms set to pour the 91 cm dia. x 45 cm deep (36" x 18") steel reinforced concrete transducer support pads.

It was absolutely critical that the electronic transducers be installed within $\pm$ 1% of level to assure their correct operation. Thusly, it was important that the concrete support pads be poured and exactly levelled for the transducer bottom support plate. The top support plates had to be levelled and shimmed against their respective 8" WF I-beams which had to be welded to the underside of the lysimeter. After allowing for an adequate concrete cure time of the support pilings, the electronic transducers (3) were attached to their respective base support plates and the lysimeter gently lowered onto them (Figure 1).

It was considered desirable to extensively modify portions of the equipment/instrument well and the outer cylinder to facilitate future access to the underside of the lysimeter and to the three transducers should their replacement ever be required. This was readily accomplished in the field through the addition of sections of CMP to the existing outer cylinder, and connection of the instrument well by means of a passage to one of the three access ports corresponding to the three transducer positions (Figure 2).

After connection and testing of the new transducer package the lysimeter was backfilled, returned to natural grade and restored as nearly as possible to natural conditions.

Field test data shows the modified lysimeter has a sensitivity of detecting a change of 0.19 mm of water over its surface area (12.56 m^2), or in other words, is capable of detecting $\pm$ 2.36 kg. This compares favorably with the specifications supplied by Transducers, Inc. which state that the electronic system is stable at the 1.0 mv single output level which would be equivalent to a theoretical sensitivity of $\pm$ 2.36 kg. We consider this to be a realistic practical sensitivity attainable with a monolith lysimeter.

In addition to this high degree of sensitivity (for a non-beam balance lysimeter) we have also eliminated any differential loading problems which tended to exist with the multiple hydraulic tube design. Loading can take place virtually at any point or points within the surface area of the lysimeter and the integrating circuitry automatically compensates giving a consistent and exact weight in each case.

The response time calculated with the hydraulic transducers lysimeter was approximately 300 seconds. The response time for the electronic strain gage transducer lysimeter is instantaneous.

The electronic transducer package is not sensitive to temperature within the range encountered in the field. The hydraulic transducer lysimeter appeared to be highly responsive to temperature changes and caused real problems when temperatures fell below freezing. Another problem not encountered by the electronic transducer is that in a hydraulic system, a very sensitive differential pressure transducer is needed to convert changes in pressure to an electrical output for continuous recording.

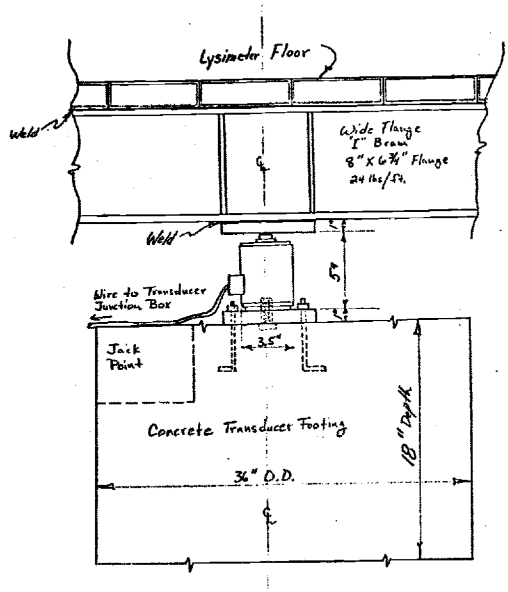

Figure 1. Plan View of Electronic Transducer

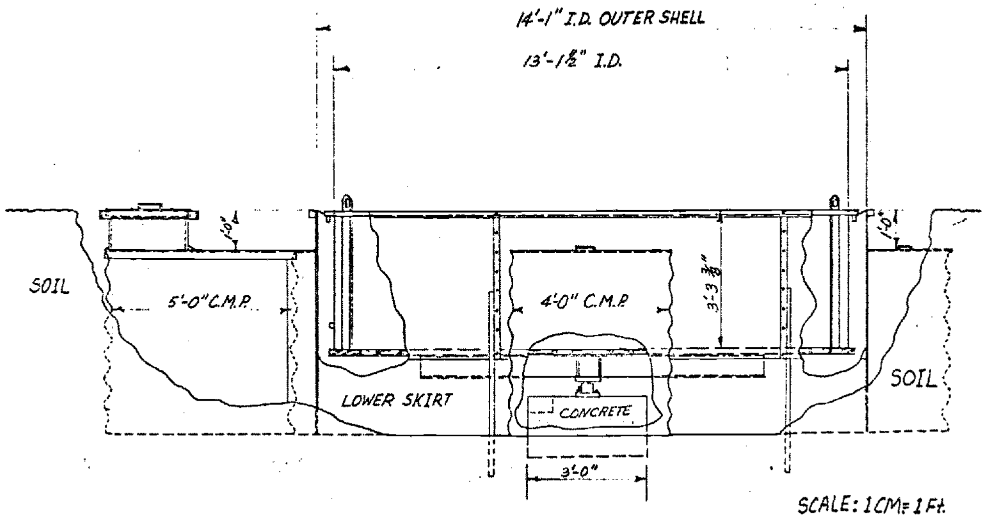

Figure 2. Plan View of Lysimeter, Electronic Transducer, and Access Equipment Wells

This instrument is subject to all the inherent problems in electronic instability plus the instability of the hydraulic system. Wind movement tended to set up pressure waves that caused the output from the pressure transducer to contain large amounts of noise. Also, it was necessary to constantly change the dummy head to remain within the range of measurement for the pressure transducer.

The only practical problem associated with the electronic strain gage transducer design is that at the high gain amplification required by the electronic package there is a tendency for the 0 output (no load position) to drift slightly. This introduces error in the reading from one time interval to the next. The method to correct this problem has been to re-zero the output from the electronics using a load simulator box supplied by Transducers, Inc., before each reading.

The biggest advantage of the electronic transducer system compared to the hydraulic system is that if any part of the electronic strain gage system fails for any reason, the individual transducer can be removed from under the lysimeter using a simple hydraulic jack, and the transducer returned to the factory for repair. In a hydraulic system if any part of the system fails the lysimeter becomes inoperable until a large amount of time and money are spent in trying to repair it.

All in all, we definitely feel that the present lysimeter design with the electronic strain gage transducers is vastly superior to the hydraulic transducer systems.

Detailed design and construction plans and notes are available from the authors upon request.

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