IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF COLORADO

Civil Action No. 11-cv-03249-WYD-CBS

SHEEP MOUNTAIN ALLIANCE, a Colorado non-profit corporation,

Plaintiff,

v.

PACIFICORP, an Oregon corporation,

Defendant.

PROPOSED CONSENT DECREE

WHEREAS, the Plaintiff, Sheep Mountain Alliance ("Plaintiff" or "SMA"), initiated the above-captioned action (the "Lawsuit") by filing a Complaint (ECF No. 1) on December 12, 2011, against PacifiCorp ("Defendant" or "PacifiCorp"), alleging violations of the Federal Water Pollution Control Act, 33 U.S.C. § 1251 *et seq.* (hereinafter, the "Clean Water Act"), and seeking declaratory and injunctive relief, civil penalties, and attorneys' and expert witness fees and costs;

WHEREAS, SMA's claims and this Consent Decree relate to the Silver Bell Tailings Impoundment (the "Impoundment"), a former mill tailings disposal site located south of Telluride, Colorado, on the west side of the Ophir Loop on Colorado State Highway 145, about one-quarter mile west of the turnoff to the town of Ophir, Colorado, as depicted in Figure 1;

WHEREAS, PacifiCorp denies SMA's claims, allegations, and any liability for the alleged violations;

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WHEREAS, SMA and PacifiCorp (collectively referred to as the "Parties" and each singularly as a "Party") agree that settlement of this matter is in the best interest of the Parties and the public, and that entry of this Consent Decree without additional litigation is the most appropriate means of resolving this Lawsuit; and

WHEREAS, SMA and PacifiCorp, after consultation with their respective counsel and without trial or final adjudication of the issues of fact or law with respect to SMA's claims or allegations, consent to the entry of this Consent Decree in order to avoid the risks of litigation and to resolve the controversy between them;

NOW, THEREFORE, upon the consent of the Parties, and upon consideration of the mutual promises herein contained, it is hereby ORDERED, ADJUDGED, AND DECREED as follows:

General Provisions

1. This Court has jurisdiction over the Parties and the subject matter of this Lawsuit pursuant to 33 U.S.C. § 1365(a) and 28 U.S.C. § 1331. Venue is proper in this Court pursuant to 33 U.S.C. § 1365(c), and 28 U.S.C. §§ 1391(b) and 1395(a). This Court shall have continuing jurisdiction over this Lawsuit for the purposes of interpretation, enforcement, and, if necessary, modification of this Consent Decree.

2. The undersigned representative for each Party certifies that he/she is fully authorized by the Party whom he/she represents to enter into the terms and conditions of this Consent Decree and to legally bind the Party to it.

3. This Consent Decree shall apply to and be binding upon the Parties to this Lawsuit, and upon all successors and assigns of the Parties. Any entity that purchases the Impoundment shall

be subject to the terms of this Consent Decree, unless otherwise agreed by the Parties through a modification to this Consent Decree under Paragraph 24. PacifiCorp, and any of its successors or assigns, may sell the Impoundment without SMA's consent and without approval by the Court. Until this Consent Decree is terminated, notice of any sale must be provided to SMA.

Site Inspections & Record Keeping

4. For the duration of this Consent Decree, representatives of SMA shall be allowed to inspect the Impoundment up to twice per year, unless otherwise agreed by the Parties. SMA shall be allowed to designate up to three individuals to take part in any inspection of the Impoundment. Prior to conducting any inspection of the Impoundment, SMA representatives shall sign any reasonable waiver or release document presented by PacifiCorp, which releases PacifiCorp from all liability for any injury, loss, or damage SMA's representatives may incur during any inspection that is not the result of negligence by PacifiCorp. Unless expressly waived by PacifiCorp in writing, SMA's representatives shall be accompanied by representatives of PacifiCorp during any site inspection.

5. SMA shall provide at least fourteen (14) days prior written notice to PacifiCorp of its desire to inspect the Impoundment under Paragraph 4, unless otherwise agreed by the Parties. Any inspection shall be scheduled for a date and time that PacifiCorp and SMA determine is mutually agreeable.

6. For the duration of this Consent Decree, PacifiCorp shall provide to SMA, at SMA's request and at no cost to SMA, either hard or electronic copies of any reports, correspondence, or other documents provided to Water & Environmental Technologies ("WET"), WET's contractors, or state or other regulatory agencies relating to the Adaptive Management Plan

described in Paragraphs 7–14 of this Consent Decree. WET was jointly chosen by the Parties to develop and implement the Adaptive Management Plan. Accordingly, PacifiCorp may not withhold from production to SMA any documents provided to WET concerning the work related to this Consent Decree. PacifiCorp may withhold from production to SMA any document that is protected under any evidentiary privilege or production immunity, including but not limited to the attorney-client privilege and work-product immunity. If PacifiCorp asserts that a document is immune from production to SMA, PacifiCorp shall provide to SMA, in the form of a privilege log, a description of the nature of the documents withheld in a manner that, without revealing privileged or protected information, will enable SMA to assess for itself whether the privilege is being properly asserted.

Adaptive Management Plan

7. PacifiCorp shall implement an Adaptive Management Plan at the Impoundment, as described below. This Adaptive Management Plan has been designed by each Party's respective experts in collaboration and in consultation with David Erickson of WET. For the purposes of the Adaptive Management Plan, each Party agrees to be bound by the final opinions and conclusions of WET as to any of the requirements set out below. PacifiCorp agrees to contract exclusively with WET for completion of all tasks required by the Adaptive Management Plan, except that PacifiCorp, with WET's prior approval, may engage, at the direction and under the oversight of WET, any necessary subcontractor to carry out the Adaptive Management Plan.

8. PacifiCorp shall be responsible for all fees and costs incurred in undertaking the Adaptive Management Plan, including compensating WET.

9. The target start date for Tasks 1–3, as set out below, shall be no later than June 15, 2013. If the Impoundment is not safely accessible by June 15, 2013, by non-winterized vehicles via the United States Forest Service access road to the Impoundment from Colorado State Highway 145 (the "Access Road"), however, then Tasks 1–3 will commence as soon as the Impoundment is safely accessible by non-winterized vehicles via the Access Road. If the target start date is delayed, PacifiCorp shall promptly notify SMA in writing of such delay and include a new projected start date.

10. *Adaptive Management Plan Task One—Double Ring Infiltrometer Testing:*

a. PacifiCorp shall complete the Double Ring Infiltrometer Test as described in WET's Investigation Work Plan (attached hereto as Exhibit A) and Attachment A to the Investigation Work Plan.

b. The data obtained from the Double Ring Infiltrometer Test shall be used to determine the in-place permeability of the current evapotranspiration cap on the Impoundment.

11. *Adaptive Management Plan Task Two—Lysimeter Installation:*

a. PacifiCorp shall complete lysimeter installation at three locations on the Impoundment, as depicted in Figure 1 of Exhibit A attached hereto.

b. The lysimeters will provide for direct measurement of moisture transmission through the current evapotranspiration cap of the Impoundment. Data from the lysimeters, along with data from a solar-powered weather station at the Impoundment, shall be collected monthly.

c. The Parties anticipate that Task Two shall be completed by October 31, 2014; however, the Parties acknowledge that completion of Task Two will depend upon the quality of the data obtained from the lysimeters and the weather station, and that additional monitoring may be required to generate useable data.

12. *Adaptive Management Plan Task Three—Ground-Penetrating Radar:*

a. PacifiCorp shall complete a geophysical survey along the southeast edge of the Impoundment using ground-penetrating radar. The purpose of Task Three is to map the bedrock surface and the thickness of the tailings or unconsolidated sediments in the Impoundment. Piezometer data will be used to determine the saturated thickness of any unconsolidated sediments that are found.

b. If, in the opinion of WET's David Erickson, the data collected during the ground-penetrating radar and piezometer study indicate that groundwater is flowing into the tailings in the Impoundment, then slug tests will be conducted using nearby piezometers to (a) determine the permeability of the saturated zone, and (b) allow WET to perform a flux calculation to determine the volume of groundwater entering the Impoundment.

c. PacifiCorp shall excavate test pits on the upgradient side of the Impoundment's stormwater control ditches in areas of possible bedrock troughs to collect data on soil type, saturation, and depth to bedrock. These data, along with ground-penetrating radar survey and piezometer data, shall be used to determine if saturation is present beneath the stormwater control ditches.

13. *Task Four—Cap Modification Modeling:*

a. Upon completion of Tasks One through Three, PacifiCorp shall model the performance of the current evapotranspiration cap using an unsaturated flow model designed specifically for evapotranspiration caps.

b. Once the model has been calibrated to present conditions at the Impoundment as reflected by the data collected and analyzed in Tasks One through Three, PacifiCorp shall evaluate the following alternatives for improving the current evapotranspiration cap: (1) installation of a new low-permeability clay cap; (2) provision of additional cover thickness; (3) construction of additional slope from the top of the tailings pile; and (4) adding a geomembrane clay liner ("GCL"). PacifiCorp also may evaluate other alternatives to improving the evapotranspiration cap and the effect a combination of alternatives will have on improving the current evapotranspiration cap.

c. PacifiCorp shall begin implementation of Task Four as soon as reasonably practicable, but in any event no later than December 31, 2014; provided, however, that if Tasks One through Three have not been completed by December 31, 2014, then PacifiCorp shall begin implementation of Task Four within fourteen (14) days after Tasks One through Three have been fully completed.

14. *Task Five—Report and Recommendation:*

a. Within sixty (60) days of the date of completion of Task Four, WET shall prepare a "Report and Recommendation" documenting the findings from Tasks One through Four. The "Report and Recommendation" shall include:

i. A complete water-balance equation, with all parameters defined and described for the site-specific conditions of the Impoundment;

ii. A detailed description of the modeling assumptions and results;

iii. Recommendations for upgrade(s) to the existing evapotranspiration cap, along with cap options and corresponding performance estimates;

iv. An estimate of the amount of time required to drain the Impoundment if the recommended modifications to the cap are implemented;

v. An estimate of the seepage rate over time resulting from implementation of the recommended modifications; and,

vi. A calculation of the expected rate of discharge and expected concentration of the effluent parameters for which effluent limitations have been established in PacifiCorp's Colorado Discharge Permit System permit (Permit No. CO-0046931) ("Permit") as of the time the "Report and Recommendation" is prepared at the following locations:

1. At a location above Outfall 001 (as defined in the Permit), upstream of any component of the water-treatment system associated with Outfall 001; and

2. At Outfall 002 (as defined in the Permit).

This calculation is hereinafter referred to as the Effluent Parameter Discharge Calculation.

b. PacifiCorp shall install the upgrade(s) recommended in WET's "Report and Recommendation" if David Erickson concludes with a high degree of confidence that installation of the upgrade(s) will decrease the amount of water infiltrating into the Impoundment such that the Effluent Parameter Discharge Calculation for all effluent parameters results in values below the discharge limits established in the Permit as of the date on which WET completes the "Report and Recommendations."

c. PacifiCorp shall begin implementation of the upgrade(s) required by subparagraph (b), if any, as soon as the Impoundment is safely accessible by non-winterized vehicles via the Access Road after WET completes the "Report and Recommendations," provided, however, that if PacifiCorp, with reasonable diligence, is unable to secure all permits and governmental approvals necessary to perform the upgrade(s) by that date, then PacifiCorp shall begin implementation of the upgrade(s) as soon as reasonably practicable after PacifiCorp has obtained all such permits and approvals.

15. If at any time the total cost incurred by PacifiCorp to undertake Tasks One through Four of the Adaptive Management Plan (as described in Paragraphs 9–12 of this Consent Decree) is projected to exceed $100,000, PacifiCorp and SMA agree to evaluate and confer in good faith regarding whether to proceed to upgrade the evapotranspiration cap or implement other improvements at the Impoundment, without further analysis and evaluation provided for by Tasks One through Four of the Adaptive Management Plan. Furthermore, SMA believes that the best approach to reduce discharges from the Impoundment is to install a geosynthetic clay liner ("GCL") cap on the Impoundment. Should PacifiCorp decide to install a GCL cap at any time prior to completing Tasks 1–5, PacifiCorp shall so inform SMA. If such a decision is reached by

PacifiCorp, Task 3 shall still be completed and any recommendations concerning groundwater infiltration shall be considered and adopted as necessary according to the Effluent Parameter Discharge Calculation to achieve the discharge limits in the Permit (as set forth in the Permit effective as of the date of the decision to install a GCL cap).

Payment in Lieu of Civil Penalties

16. Within forty-five (45) days from the date this Consent Decree is entered by the Court, PacifiCorp shall pay $150,000 toward the supplemental environmental project ("SEP") related to improvement of water quality within the San Miguel River watershed as identified in Exhibit B, attached hereto. At no time shall PacifiCorp be required to fund a SEP that would cause PacifiCorp to manage or administer the SEP in any manner or become legally responsible in any way for any remediation or other tasks occurring at the SEP, or for any other liability whatsoever. PacifiCorp's only involvement in the SEP shall be the payment of funds as expressed herein. Should the project identified in Exhibit B not proceed, the funds to be paid by PacifiCorp shall be placed in escrow, on such terms and conditions to be determined and agreed to by the Parties, until such time as the Parties agree on an alternative SEP, or SEPs, within the San Miguel River Watershed.

Payment of Legal Expenses

17. Within twenty (20) days from the date this Consent Decree is entered by the Court, PacifiCorp shall pay for SMA's attorneys' and consultation fees and costs incurred in association with this Lawsuit, in the amount of $250,000. PacifiCorp shall pay such attorneys' and expert consultation fees and costs to the Law Offices of Charles M. Tebbutt, P.C. SMA's attorneys and experts shall be solely responsible for any taxes that may be applicable to such fees and costs.

Force Majeure

18. A "Force Majeure Event" shall mean an event that has been or will be caused by circumstances beyond the control of PacifiCorp, its contractors, or any entity controlled by PacifiCorp, or WET, its contractors, or any entity controlled by WET, that delays or prevents performance of any provision of this Consent Decree despite the best efforts of PacifiCorp, its consultants, or any entity controlled by PacifiCorp, to fulfill the obligation. "Best efforts to fulfill the obligation" include using due diligence to anticipate any potential Force Majeure Event and to address the effects of any such event (a) as it is occurring and (b) after it has occurred, such that the delay or non-compliance is minimized to the greatest extent possible. Failure of a permitting authority to issue a necessary permit in a timely fashion may constitute a Force Majeure Event where PacifiCorp has taken all reasonable actions to obtain the permit by the time necessary to comply with any applicable deadlines established in this Consent Decree. Such delay in or failure of performance occasioned by a Force Majeure Event shall not be deemed a violation of this Consent Decree.

19. If any event occurs or has occurred that may delay or prevent performance of any obligation under this Consent Decree as to which PacifiCorp intends to assert a claim of Force Majeure, PacifiCorp shall notify SMA in writing as soon as practicable, but in no event later than ten (10) business days following the date PacifiCorp first knew of the claimed Force Majeure Event. In this notice, PacifiCorp shall describe the anticipated length of time that the delay or prevention of performance may persist, the cause or causes of the delay or prevention of performance, all measures taken or to be taken by PacifiCorp to prevent or minimize the delay or prevention of performance, the schedule by which PacifiCorp proposes to implement those

measures, and PacifiCorp's rationale for attributing a delay or prevention of performance to a Force Majeure Event.

20. SMA shall notify PacifiCorp in writing if it does not accept PacifiCorp's claim of Force Majeure within ten (10) days of receipt of the notice asserting the claim provided under Paragraph 18. Failure by SMA to provide such timely notice shall be deemed acceptance of the asserted Force Majeure claim. If the Parties agree that a delay in performance has been or will be caused by a Force Majeure Event, the Parties shall stipulate to an extension of deadline(s) for performance of the affected compliance requirement(s). In such circumstances, an appropriate modification shall be made pursuant to Paragraph 24.

21. If SMA does not accept PacifiCorp's claim of Force Majeure, or if SMA and PacifiCorp cannot agree on the length of the delay actually caused by the Force Majeure Event, the matter shall be resolved in accordance with Paragraph 25.

Resolution of Claims

22. This Consent Decree constitutes the exclusive remedy and final resolution between PacifiCorp and SMA, along with its members, officers, or directors, for all alleged violations of the Clean Water Act set forth in the Complaint and sixty-day notices of intent to sue sent by SMA to PacifiCorp on October 11, 2011 and January 13, 2012 (attached hereto as Exhibits C and D, respectively) ("60-Day Notices") that may have occurred or that could have been raised prior to the entry of this Consent Decree.

23. SMA releases and covenants not to sue PacifiCorp, and its directors, officers, employees, and agents, with respect to any claims under the Clean Water Act or any other federal or state law or regulation that were or could have been brought in this lawsuit arising from any act or

omission by PacifiCorp in regard to the Impoundment that occurred before the date the Court enters this Consent Decree. This release and covenant not to sue includes all such claims, whether known or unknown, asserted or unasserted, and specifically includes claims for damages, civil penalties, attorneys' fees and costs, expert consultant and witness fees, and injunctive relief.

24. Within five (5) days following entry of this Consent Decree by the Court, SMA shall withdraw its pending administrative challenge to the Permit before the Colorado Department of Public Health and Environment ("CDPHE"), including SMA's request under Colorado Water Quality Control Commission Regulations 61.7(a) and 21.4(B) for an adjudicatory hearing in regard to the Permit. From the date this Consent Decree is entered and until it is terminated, SMA further covenants not to initiate, commence, finance, or participate in any administrative, judicial, or other action to challenge the validity, terms, or any other aspect of the Permit.

Modification

25. Modifications to this Consent Decree may be made only upon written agreement of the Parties. Material modifications shall be effective only upon approval by the Court. Extension by mutual agreement of the Parties of any deadline under this Consent Decree by not more than sixty (60) days is not a material modification and does not require Court approval.

Dispute Resolution

26. In the event of any dispute regarding implementation, interpretation, application, or compliance with this Consent Decree, the Parties shall first attempt to informally resolve that dispute through meetings of the Parties. Any Party may initiate this informal dispute resolution process by serving written notice of a request for dispute resolution on the other Party. If no

resolution is reached within thirty (30) days from the date that the notice of a request for dispute resolution is served, then the Parties may resolve the dispute by filing motions with the Court.

Termination

27. This Consent Decree shall terminate upon the first occurrence of any of the following: (1) completion of the Adaptive Management Plan, including installation of upgrades, if any, recommended in WET's "Report and Recommendation"; or, (2) dissolution of this Consent Decree by the Court.

Miscellaneous Provisions

28. By entering into the Consent Decree, the Parties are not admitting any fact or conclusion of law, and this Consent Decree shall not constitute an admission, statement, or evidence of any fact, wrongdoing, misconduct, or liability on the part of PacifiCorp, its owners, officers, agents, consultants, or affiliated entities.

29. The Parties recognize that no consent judgment can be entered in a Clean Water Act suit in which the United States is not a party prior to forty-five (45) days following the receipt of a copy of the proposed Consent Decree by the Attorney General of the United States and the Administrator of the Environmental Protection Agency pursuant to 33 U.S.C. § 1365(c)(3). Upon execution of this Consent Decree by the Parties, SMA shall serve copies of the executed Consent Decree upon the Administrator of the United States Environmental Protection Agency, the Attorney General, and the Regional Administrator for EPA Region 8, and SMA shall provide notice to the Court of the foregoing requirements, all as required pursuant to 40 C.F.R. § 135.5.

30. This Consent Decree constitutes the final, complete, and exclusive agreement and understanding of the Parties with respect to the settlement embodied in this Consent Decree and

the subject matter of the Lawsuit. The Parties hereby acknowledge that there are no representations or understandings relating to the Lawsuit or its settlement other than those expressly contained in this Consent Decree.

31. The Parties agree to share any press releases regarding this Consent Decree, settlement of this Lawsuit, or any other matter related thereto on or before the business day prior to issuing such release solely for the purpose of providing the other Party with notice and a copy of the press release.

32. In the event that any part of this Consent Decree is deemed by a court of competent jurisdiction to be unlawful, void, or for any reason unenforceable, and if that part is severable from the remainder of the Consent Decree without frustrating its essential purpose, then the remaining parts of this Decree shall remain valid, binding, and enforceable.

33. Each Party acknowledges and represents that it has relied on the legal advice of its attorneys, who are the attorneys of its own choice, and that the terms of this Consent Decree have been completely explained to the Party by its attorneys, and that the terms are fully understood and voluntarily accepted. SMA has been represented by Charles M. Tebbutt and Daniel C. Snyder of the Law Offices of Charles M. Tebbutt, P.C. PacifiCorp has been represented by Andrew C. Lillie and Aaron M. Paul of Hogan Lovells US LLP.

34. If for any reason the Court should decline to approve this Consent Decree in the form presented, then the Parties agree to continue negotiations in good faith in an attempt to cure any objection raised by the Court to entry of this Decree.

35. This Consent Decree may be signed in counterparts, and such counterpart signature page shall be given full force and effect.

Notices

36. Whenever notice is required to be given or a document is required to be sent by one Party to another under the terms of this Consent Decree, it will be directed to the individuals at the addresses specified below, unless prior notice of a change has been given to the other Party. A notice is sufficient under this Consent Decree if it is provided in writing through U.S. mail, hand-delivered, or provided electronically by e-mail with proof of delivery receipt certificate requested. If notice is provided via U.S. mail, it shall be considered effective upon the date of mailing.

For Plaintiff SMA:

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Daniel C. Snyder
Law Offices of Charles M. Tebbutt, P.C.
941 Lawrence St., Eugene OR 97401
Tel: (541) 344-3505
Fax: (541) 344-3516
charlie.tebbuttlaw@gmail.com
dan.tebbuttlaw@gmail.com

And to:

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Director, Sheep Mountain Alliance
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Hilary@sheepmountainalliance.org

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Aaron M. Paul
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aaron.paul@hoganlovells.com

And to:

Michael G. Jenkins
PacifiCorp Energy
1407 West North Temple, Suite 320
Salt Lake City, Utah 84121
michael.jenkins@pacificorp.com

Effective Date

37. The effective date of this Consent Decree shall be the date upon which the Clerk enters in the civil docket a copy of this Consent Decree signed by the Court.

Final Judgment

38. Upon approval and entry of this Consent Decree by the Court, this Consent Decree shall constitute a final judgment of the Court under Rules 54 and 58 of the Federal Rules of Civil Procedure.

WE HEREBY CONSENT to the Entry of this Consent Decree

Dated and Entered this ____ Day of ______________, 2013.

____
WILEY Y. DANIELS
United States District Court Judge

For Plaintiff Sheep Mountain Alliance:

Signature: Hilary N Cooper

Name: Hilary Cooper

Position: Executive Director, Sheep Mountain Alliance

Date: March 18, 2013

For Defendant PacifiCorp:

Signature: Dean Brockbank

Name: Dean Brockbank

Position: General Counsel

Date: March 15, 2013

Sheep Mountain Alliance v. Pacificorp, 11-cv-03249-WYD-CBS

Consent Decree—Figure 1

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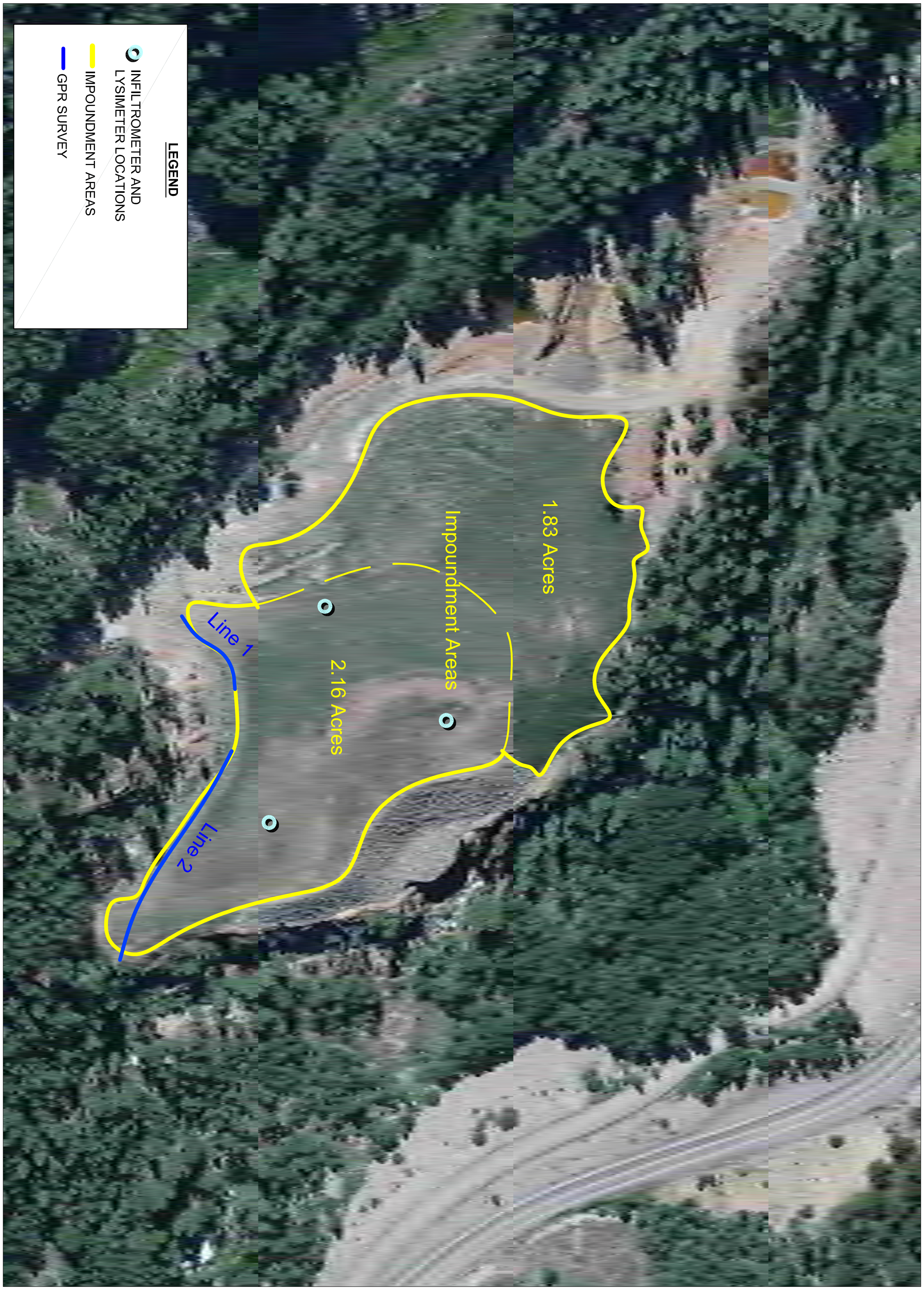

SHEET 1 of 1

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JOB # PERCM34
DATE: 1/18/2013
DESIGNER: MAT
CHK'D BY: DE

SCALE 1" = 100'
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Water & Environmental Technologies PC hereby reserves our common law copyright in this document and the ideas and designs incorporated herein as an instrument of professional service which shall not be used in whole or part for any other projects or other use without our express written authorization.

SILVER BELL MINE
PRELIMINARY DESIGN

SITE MAP

COLORADO

WATER & ENVIRONMENTAL TECHNOLOGIES, PC

Suite 200
480 E. Park Street
Butte, MT 59701
(406)-782-5220

Suite 103
1321 8th Ave N.
Great Falls, MT 59401
(406)-782-5220

PRELIMINARY NOT FOR CONSTRUCTION

No.	Revision/Issue	Date

Sheep Mountain Alliance v. Pacificorp, 11-cv-03249-WYD-CBS

Consent Decree—Attachment A

Investigation Work Plan

Silver Bell Mine Site

Telluride, Colorado

Introduction

This work plan is written to define the work tasks and methods needed to determine if the seepage emanating from the tailings pile can be attributed to recharge entering the cap. In order to accomplish these tasks, ground water infiltration and surface water run on must be investigated and eliminated from the equation, if possible. If these sources of water can be eliminated (ie. are not currently contributing to the seepage), then a cap upgrade could eliminate the need for water treatment and result in a dry closure of the tailings pile.

We can break the seepage volume down to a simple equation:

$$S = P - ET + G_{in} - G_{out} + SW_{runon} - SW_{runoff}$$

Where:

- S = Seepage
- P = Precipitation
- ET = Evapotranspiration
- G_{in} = Ground Water Run On
- G_{out} = Ground Water Run Off
- SW_{runon} = Surface Water Run On
- SW_{runoff} = Surface Water Run Off

If we can eliminate the possibility of ground water entering the tailings and verify the exclusion of all surface water entering the capped area, then:

$$S = Recharge = P\text{-}ET$$

Therefore, in analyzing whether all seepage could be a result of infiltration, we can calculate seepage rates based on general site data and assumptions:

*4 acres *43,560 ft^2/acre * 24 inches precipitation per year * 1 ft/12 in * 10% infiltration (Standard Assumption) *7.48 gal/ ft^3 / (365 days/year * 1440 min/day) =* ***0.5 gallons per minute***

Methodology

In order to define the terms of the equations and collect the information needed to reasonably model existing and future cap performance, the following testing will be conducted. The permeability of the cap will be determined using a double ring infiltrometer at three locations on the cap. Evapotranspiration will be identified by installing three lysimeters and collecting site specific precipitation data. Ground water inflow, if present, will be identified and defined by using ground penetrating radar to map the saturated alluvium and bedrock surface on the upgradient edge of the pile and using subsurface permeability and site gradient to calculate the ground water flux. Finally, all the data will be compiled and used to model the performance of the existing cap and determine the needed upgrades to prevent recharge, if possible. A final report with project details and modeling results will be prepared and submitted.

Task 1. Double Ring Infiltrometer Testing

The purpose of the double ring infiltrometer test is to determine the in-place permeability of the cap material. This data will be used to model current cap conditions and future design options. The tests will be conducted in the vicinity of the lysimeters. The detailed testing procedure is documented in Attachment A.

Task 2. Lysimeter Installation (P & ET)

Lysimeters will be installed at the three locations shown on Figure 1. The lysimeters will collect water to directly measure moisture transmission through the cap. Monthly monitoring of moisture will be required along with data collection from a solar powered weather station. The precipitation rates can be directly compared with seepage rates from the lysimeters to determine infiltration rates through the cap and evapotranspiration.

Task 3. Ground Penetrating Radar (ΔG & ΔS)

A geophysical survey will be conducted along the southeast edge of the tailings pile. Ground penetrating radar will be used to map the bedrock surface and thickness of tailings or unconsolidated sediments. Piezometer data will be used to determine the saturated thickness of unconsolidated sediments. If the data suggests that there is ground water flowing into the tailings, slug tests will be conducted in nearby piezometers to determine the permeability of the saturated zone and allow a flux calculation to determine the volume of ground water entering the site.

Additional data will be collected around the storm water control ditches to look at depth to bedrock and vadose zone saturation. These data will be used to determine if storm water is contributing to the seepage.

Task 4. Cap Modification Modeling

Once the data from the above mentioned testing is compiled, the cap performance will be modeled using an unsaturated flow model designed specifically for cap designs. The field data will allow an accurate calculation of the recharge volume moving through the cap and the resulting seepage into the water treatment system. Once the model is calibrated to present conditions, additional scenarios can be tested for cap improvements. For example: installation of a low permeability clay cap, additional cover thickness, installation of additional slope on the top of the tailings and/or a geomembrane clay liner (GCL) can be simulated with the model to determine the best cap design for the specific conditions at the site.

Task 5. Report & Recommendations

Once the data is collected and compiled and the modeling is complete, a final summary report will be completed to document the findings, model results and recommended upgrades, if appropriate.

The report will include:

1. A complete water balance equation, with all parameters defined and described for the site specific conditions.
2. A detailed description of the modeling assumptions and results.
3. Recommendations for the final cap, along with cap options and corresponding performance estimates.
4. An estimate of the amount of time required to drain the tailings pile if modifications to the cap are recommended.
5. An estimate of the seepage rate over time resulting from any site upgrades.
6. A calculation of expected discharge rate and concentration to determine compliance with the discharge permit.

Schedule

Task	Description	Schedule
1	Double Ring Infiltrometer	June - July 2013
2	Lysimeter Installation & Data Collection	June 2013 – October 2014*
3	Ground Penetrating Radar	June - July 2013
4	Cap Modification Modeling	October – December 2014
5	Reporting	January 2015

*Dependent on Data Quality from Lysimeter

Attachment A. Double Ring Infiltrometer Test

Designation: D3385 – 09

Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer[1]

This standard is issued under the fixed designation D3385; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This test method describes a procedure for field measurement of the rate of infiltration of liquid (typically water) into soils using double-ring infiltrometer.

1.2 Soils should be regarded as natural occurring fine or coarse-grained soils or processed materials or mixtures of natural soils and processed materials, or other porous materials, and which are basically insoluble and are in accordance with requirements of 1.5.

1.3 This test method is particularly applicable to relatively uniform fine-grained soils, with an absence of very plastic (fat) clays and gravel-size particles and with moderate to low resistance to ring penetration.

1.4 This test method may be conducted at the ground surface or at given depths in pits, and on bare soil or with vegetation in place, depending on the conditions for which infiltration rates are desired. However, this test method cannot be conducted where the test surface is below the groundwater table or perched water table.

1.5 This test method is difficult to use or the resultant data may be unreliable, or both, in very pervious or impervious soils (soils with a hydraulic conductivity greater than about 10^{-2} cm/s or less than about 1×10^{-6} cm/s) or in dry or stiff soils that most likely will fracture when the rings are installed. For soils with hydraulic conductivity less than 1×10^{-6} cm/s refer to Test Method D5093.

1.6 This test method cannot be used directly to determine the hydraulic conductivity (coefficient of permeability) of the soil (see 5.2).

1.7 The values stated in SI units are to be regarded as the standard.

1.8 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D1452 Practice for Soil Exploration and Sampling by Auger Borings

D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D5093 Test Method for Field Measurement of Infiltration Rate Using Double-Ring Infiltrometer with Sealed-Inner Ring

3. Terminology

3.1 *Definitions:* For common definitions of terms in this standard, refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *incremental infiltration velocity*—the quantity of flow per unit area over an increment of time. It has the same units as the infiltration rate.

3.2.2 *infiltration*—the downward entry of liquid into the soil.

3.2.3 *infiltration rate*—a selected rate, based on measured incremental infiltration velocities, at which liquid can enter the soil under specified conditions, including the presence of an excess of liquid. It has the dimensions of velocity (that is, $cm^3 cm^{-2}\ h^{-1} = cm\ h^{-1}$).

3.2.4 *infiltrometer*—a device for measuring the rate of entry of liquid into a porous body, for example, water into soil.

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.04 on Hydrologic Properties and Hydraulic Barriers.

Current edition approved March 1, 2009. Published March 2009. Originally approved in 1975. Last previous edition approved in 2003 as D3385 – 03. DOI: 10.1520/D3385-09.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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4. Summary of Test Method

4.1 The double-ring infiltrometer method consists of driving two open cylinders, one inside the other, into the ground, partially filling the rings with water or other liquid, and then maintaining the liquid at a constant level. The volume of liquid added to the inner ring, to maintain the liquid level constant is the measure of the volume of liquid that infiltrates the soil. The volume infiltrated during timed intervals is converted to an incremental infiltration velocity, usually expressed in centimetre per hour or inch per hour and plotted versus elapsed time. The maximum-steady state or average incremental infiltration velocity, depending on the purpose/application of the test is equivalent to the infiltration rate.

5. Significance and Use

5.1 This test method is useful for field measurement of the infiltration rate of soils. Infiltration rates have application to such studies as liquid waste disposal, evaluation of potential septic-tank disposal fields, leaching and drainage efficiencies, irrigation requirements, water spreading and recharge, and canal or reservoir leakage, among other applications.

5.2 Although the units of infiltration rate and hydraulic conductivity of soils are similar, there is a distinct difference between these two quantities. They cannot be directly related unless the hydraulic boundary conditions are known, such as hydraulic gradient and the extent of lateral flow of water, or can be reliably estimated.

5.3 The purpose of the outer ring is to promote one-dimensional, vertical flow beneath the inner ring.

5.4 Many factors affect the infiltration rate, for example the soil structure, soil layering, condition of the soil surface, degree of saturation of the soil, chemical and physical nature of the soil and of the applied liquid, head of the applied liquid, temperature of the liquid, and diameter and depth of embedment of rings.[3] Thus, tests made at the same site are not likely to give identical results and the rate measured by the test method described in this standard is primarily for comparative use.

5.5 Some aspects of the test, such as the length of time the tests should be conducted and the head of liquid to be applied, must depend upon the experience of the user, the purpose for testing, and the kind of information that is sought.

NOTE 1—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Infiltrometer Rings*—Cylinders approximately 500 mm (20 in.) high and having diameters of about 300 and 600 mm (12 and 24 in.). Larger cylinders may be used, providing the ratio of the outer to inner cylinders is about two. Cylinders can be made of 3-mm (1⁄8-in.), hard-alloy, aluminum sheet or other material sufficiently strong to withstand hard driving, with the bottom edge bevelled (see Fig. 1). The bevelled edges shall be kept sharp. Stainless steel or strong plastic rings may have to be used when working with corrosive fluids.

6.2 *Driving Caps*—Disks of 13-mm (1⁄2-in.) thick hard-alloy aluminum with centering pins around the edge, or preferably having a recessed groove about 5 mm (0.2 in.) deep with a width about 1 mm (0.05 in.) wider than the thickness of the ring. The diameters of the disks should be slightly larger than those of the infiltrometer rings.

6.3 *Driving Equipment*—A 5.5-kg (12-lb) mall or sledge and a 600 or 900-mm (2 or 3-ft) length of wood approximately 50 by 100 mm or 100 by 100 mm (2 by 4 in. or 4 by 4 in.), or a jack and reaction of suitable size.

6.4 *Depth Gage*—A hook gage, steel tape or rule, or length of steel or plastic rod pointed on one end, for use in measuring and controlling the depth of liquid (head) in the infiltrometer ring, when either a graduated Mariotte tube or automatic flow control system is not used.

6.5 *Splash Guard*—Several pieces of rubber sheet or burlap 150 mm (6 in.) square.

6.6 *Rule or Tape*—Two-metre (6-ft) steel tape or 300-mm (1-ft) steel rule.

6.7 *Tamp*—Any device that is basically rigid, has a handle not less than 550 mm (22 in.) in length, and has a tamping foot with an area ranging from 650 to 4000 mm^2 (1 to 6 in.^{2}) and a maximum dimension of 150 mm (6 in.).

6.8 *Shovels*—One long-handled shovel and one trenching spade.

6.9 *Liquid Containers*:

6.9.1 One 200-L (55-gal) barrel for the main liquid supply, along with a length of rubber hose to siphon liquid from the barrel to fill the calibrated head tanks (see 6.9.3).

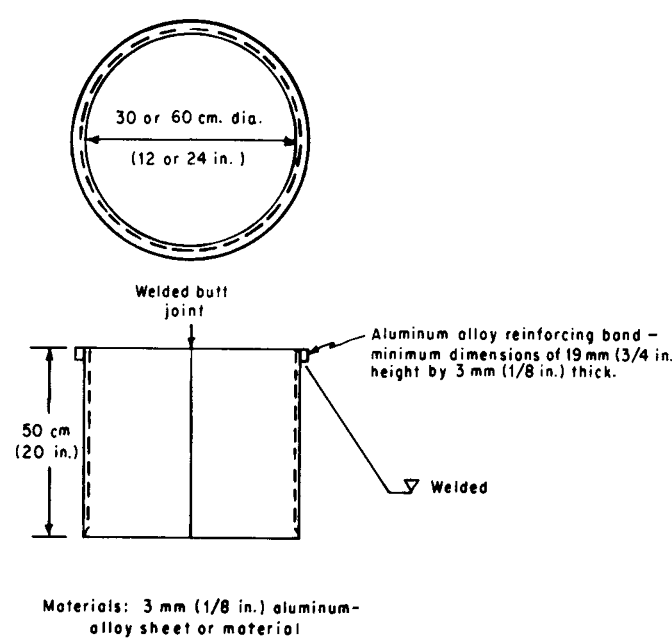

FIG. 1 Infiltrometer Construction

[3] Discussion of factors affecting infiltration rate is contained in the following reference: Johnson, A. I., *A Field Method for Measurement of Infiltration*, U.S. Geological Survey Water-Supply Paper 1544-F, 1963, pp. 4–9.

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6.9.2 A 13-L (12-qt) pail for initial filling of the infiltrometers.

6.9.3 Two calibrated head tanks for measurement of liquid flow during the test. These may be either graduated cylinders or Mariotte tubes having a minimum volume capacity of about 3000 mL (see Note 2 and Note 3 and Fig. 2).

NOTE 2—It is useful to have one head tank with a capacity of three times that of the other because the area of the annular space between the rings is about three times that of the inner ring.

NOTE 3—In many cases, the volume capacity of these calibrated head tanks must be significantly larger than 3000 mL, especially if the test has to continue overnight. Capacities of about 50 L (13 gal) would not be uncommon.

6.10 *Liquid Supply*—Water, or preferably, liquid of the same quality and temperature as that involved in the problem being examined. The liquid used must be chemically compatible with the infiltrometer rings and other equipment used to contain the liquid.

NOTE 4—To obtain maximum infiltration rates, the liquid should be free from suspended solids and the temperature of the liquid should be higher than the soil temperature. This will tend to avoid reduction of infiltration from blockage of voids by particles or gases coming out of solution.

6.11 *Watch or Stopwatch*—A stopwatch would only be required for high infiltration rates.

6.12 *Level*—A carpenter's level or bull's-eye (round) level.

6.13 *Thermometer*—With accuracy of 0.5°C and capable of measuring ground temperature.

6.14 *Rubber Hammer (mallet)*.

6.15 *pH Paper*, in 0.5 increments.

6.16 *Recording Materials*—Record books and graph paper, or special forms with graph section (see Fig. 3 and Fig. 4).

6.17 *Hand Auger*—Orchard-type (barrel-type) auger with 75-mm (3-in.) diameter, 225-mm (9-in.) long barrel and a rubber-headed tire hammer for knocking sample out of the auger. This apparatus is optional.

6.18 *Float Valves*—Two constant level float valves (carburetors or bob-float types) with support stands. This apparatus is optional.

6.19 *Covers and Dummy Tests Set-Up*—For long-term tests in which evaporation of fluid from the infiltration rings and unsealed reservoirs can occur (see 8.2.1).

7. Calibration

7.1 *Rings*:

7.1.1 Determine the area of each ring and the annular space between rings before initial use and before reuse after anything has occurred, including repairs, which may affect the test results significantly.

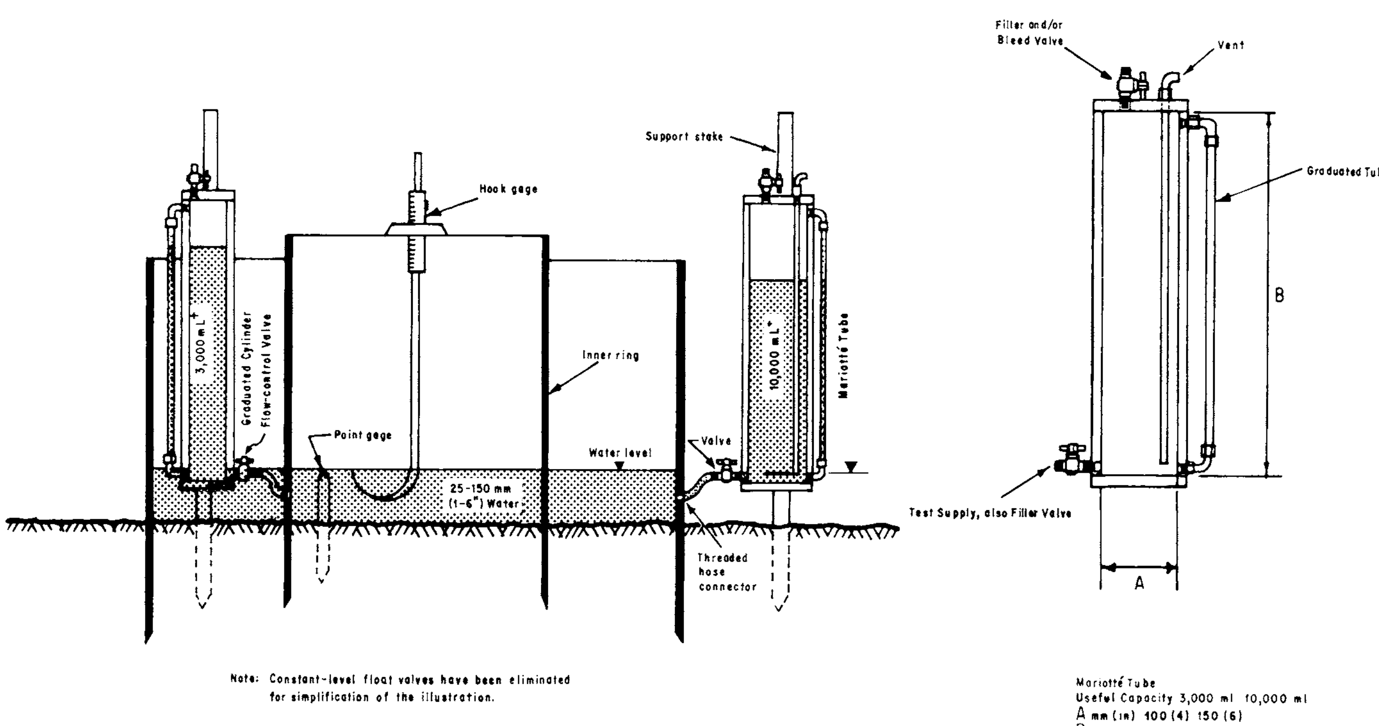
7.1.2 Determine the area using a measuring technique that will provide an overall accuracy of 1 %.

7.1.3 The area of the annular space between rings is equal to the internal area of the 600-mm (24-in.) ring minus the external area of the 300-mm (12-in.) ring.

7.2 *Liquid Containers*—For each graduated cylinder or graduated Mariotte tube, establish the relationship between the change in elevation of liquid (fluid) level and change in volume of fluid. This relationship shall have an overall accuracy of 1 %.

8. Procedure

8.1 *Test Site*:



NOTE 1—Constant-level float valves have been eliminated for simplification of the illustration

FIG. 2 Ring Installation and Mariotte Tube Details

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Project Identification NRTS
Test Location IDAHO - Lost River Alluvium
Liquid Used: River water pH = 8.0
Tested by IJA CWJ Liquid level maintained using: ☐ Flow value; ☐ Float value; ☒ Mariotte tube
Depth to water table: 5.2 (m) Penetration of rings: Inner: 7.5 (cm); Outer: 17.5 (cm)

Constants	Area (cm²)	Depth of Liquid (cm)	Liquid Containers No.	Vol/ΔH (cm³/cm)
Inner Ring	707	4.0	1	78.54
Annular Space	2106	4.1	2	176.70

Trial No.		Date 1982	Time hr:min	Elapsed Time Δ(total) min	Flow Readings: Inner Ring Reading cm	Inner Ring Flow cm³	Annular Space Reading cm	Annular Space Flow cm³	Liquid Temp °C	Infilt. Rate Inner cm/h	Infilt. Rate Annular cm/h	Ground temp. = 14°C @ depth of 30 (cm) Remarks: Weather Conditions, etc.
1	S	10/14	10:00	15	3.0	114	2.2	389	15	0.64	0.74	Cloudy, slight wind
	E	"	10:15	(15)	4.45		4.4		"			
2	S	"	10:15	15	4.45	212	4.4	795	15	1.2	1.5	
	E	"	10:30	(30)	7.15		8.9		"			
3	S	"	10:30	15	7.15	263	8.9	848	15	1.5	1.6	
	E	"	10:45	(45)	10.5		13.7		"			
4	S	"	10:45	15	10.5	306	13.7	945	15	1.7	1.8	
	E	"	11:00	(60)	14.4		19.05		15.5			
5	S	"	11:00	30	14.4	758	19.05	2324	15.5	2.1	2.2	
	E	"	11:30	(90)	24.05		32.2		16			
6	S	"	11:30	30	24.05	848	32.2	2580	16	2.4	2.45	
	E	"	12:00	(120)	34.85		46.8		16.5			
7	S	"	12:10	60	3.5	1944	2.2	5902	16.5	2.75	2.8	Refilled tubes
	E	"	13:10	(180)	28.25		35.6		17			
8	S	"	13:20	60	2.4	1877	3.2	5690	17.5	2.65	2.7	" "
	E	"	14:20	(240)	26.3		35.4		"			
9	S	"	14:30	60	4.3	1696	4.7	5054	17.5	2.4	2.4	" "
	E	"	15:30	(300)	25.9		33.3		18			
10	S	"	15:40	60	2.2	1586	4.5	4842	18	2.2	2.3	" "
	E	"	16:40	(360)	22.4		31.9		"			Cloudy, slight wind

FIG. 3 Data Form for Infiltration Test with Sample Data

8.1.1 Establish the soil strata to be tested from the soil profile determined by the classification of soil samples from an adjacent auger hole.

NOTE 5—For the test results to be valid for soils below the test zone, the soil directly below the test zone must have equal or greater flow rates than the test zone.

8.1.2 The test requires an area of approximately 3 by 3 m (10 by 10 ft) accessible by a truck.

8.1.3 The test site should be nearly level, or a level surface should be prepared.

8.1.4 The test may be set up in a pit if infiltration rates are desired at depth rather than at the surface.

8.2 *Technical Precautions*:

8.2.1 For long-term tests, avoid unattended sites where interference with test equipment is possible, such as sites near children or in pastures with livestock. Also, evaporation of fluid from the rings and unsealed reservoirs can lead to errors in the measured infiltration rate. Therefore, in such tests, completely cover the top of the rings and unsealed reservoirs with a relatively airtight material, but vented to the atmosphere through a small hole or tube. In addition, make measurements to verify that the rate of evaporation in a similar test configuration (without any infiltration into the soil) is less than 20% of the infiltration rate being measured.

8.2.2 Make provisions to protect the test apparatus and fluid from direct sunlight and temperature variations that are large enough to affect the slow measurements significantly, especially for test durations greater than a few hours or those using a Mariotte tube. The expansion or contraction of the air in the Mariotte tube above the water due to temperature changes may cause changes in the rate of flow of the liquid from the tube which will result in a fluctuating water level in the infiltrometer rings.

8.3 *Driving Infiltration Rings with a Sledge*:

NOTE 6—Driving rings with a jack is preferred; see 8.4.

8.3.1 Place the driving cap on the outer ring and center it thereon. Place the wood block (see 6.3) on the driving cap.

8.3.2 Drive the outer ring into the soil with blows of a heavy sledge on the wood block to a depth that will (*a*) prevent the test fluid from leaking to the ground surface surrounding the ring, and (*b*) be deeper than the depth to which the inner ring

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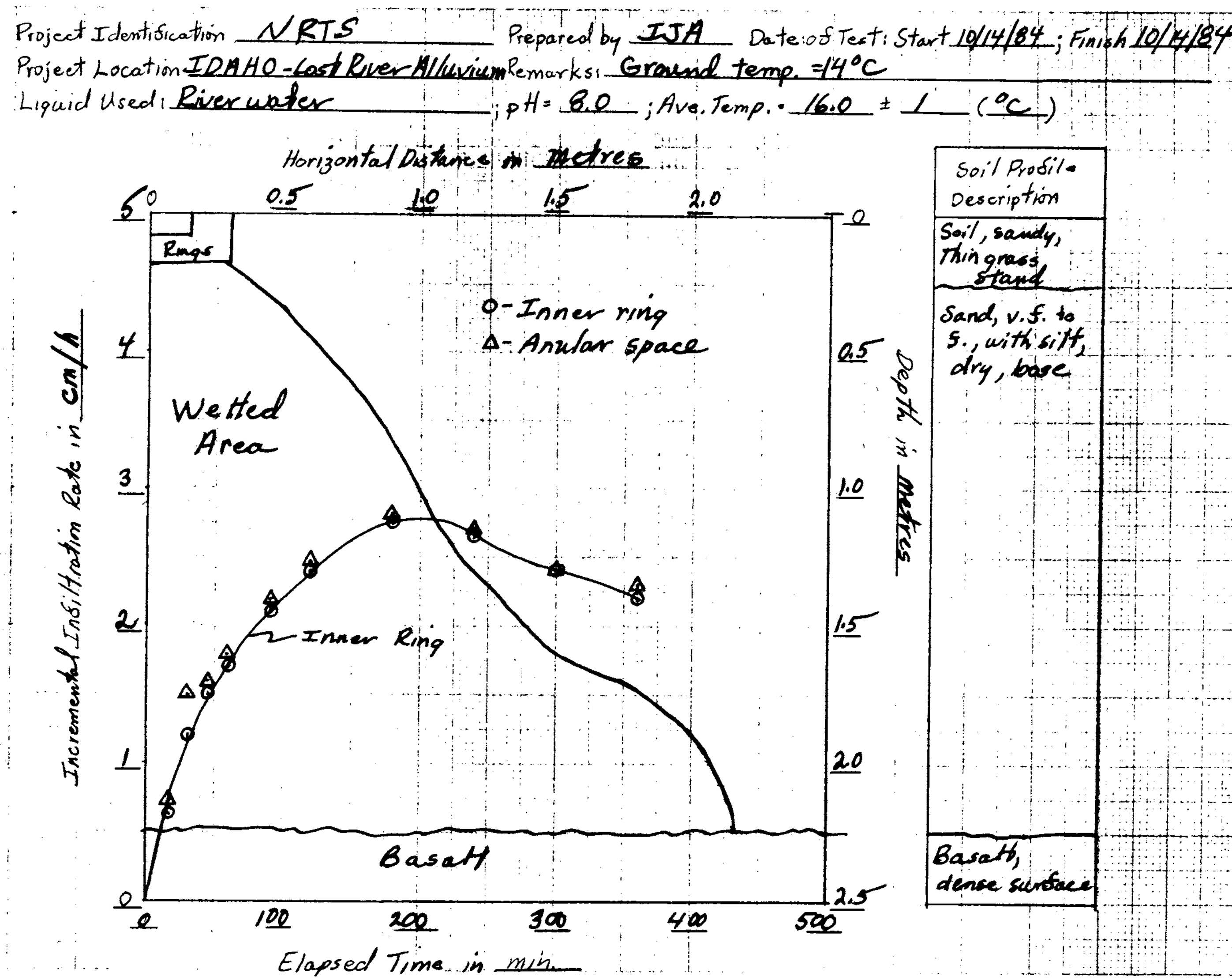

FIG. 4 Report Form for Infiltration Test With Sample Data

will be driven. A depth of about 150 mm (6 in.) is usually adequate. Use blows of medium force to prevent fracturing of the soil surface. Move the wood block around the edge of the driving cap every one or two blows so that the ring will penetrate the soil uniformly. A second person standing on the wood block and driving cap will usually facilitate driving the ring, and reduce vibrations and disturbance.

8.3.3 Center the smaller ring inside the larger ring and drive to a depth that will prevent leakage of the test fluid to the ground surface surrounding the ring, using the same technique as in 8.3.2. A depth of between about 50 and 100 mm (2 and 4 in.) is usually adequate.

8.4 *Driving Infiltration Rings with Jacks*:

8.4.1 Use a heavy jack under the back end of a truck to drive rings as an alternative to the sledge method (see 8.3).

8.4.2 Center the wood block across the driving cap of the ring. Center a jack on the wood block. Place the top of the jack and the assembled items vertically under the previously positioned end of a truck body and apply force to the ring by means of the jack and truck reaction. Also, tamp near the edges or near the center of the ring with the rubber mallet, as slight tamping and vibrations will reduce hang-ups and tilting of the ring.

8.4.3 Add additional weight to the truck if needed to develop sufficient force to drive the ring.

8.4.4 Check the rings with the level, correcting the attitude of the rings to be vertical, as needed.

8.5 *Tamping Disturbed Soil*:

8.5.1 If the surface of the soil surrounding the wall of the ring(s) is excessively disturbed (signs of extensive cracking, excessive heave, and the like), reset the ring(s) using a technique that will minimize such disturbance.

8.5.2 If the surface of the soil surrounding the wall of the ring(s) is only slightly disturbed, tamp the disturbed soil adjacent to the inside and outside wall of the ring(s) until the soil is as firm as it was prior to disturbance.

8.6 *Maintaining Liquid Level*:

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8.6.1 There are basically three ways to maintain a constant head (liquid level) within the inner ring and annular space between the two rings: manually controlling the flow of liquid, the use of constant-level float valves, or the use of a Mariotte tube.

8.6.2 When manually controlling the flow of liquid, a depth gage is required to assist the investigator visually in maintaining a constant head. Use a depth gage such as a steel tape or rule for soils having a relatively high permeability; for soils having a relatively low permeability use a hook gage or simple point gage.

8.6.3 Install the depth gages, constant-level valves, or Mariotte tubes as shown in Fig. 2, and in such a manner that the reference head will be at least 25 mm (1 in.) and not greater than 150 mm (6 in.). Select the head on the basis of the permeability of the soil, the higher heads being required for lower permeability soils. Locate the depth gages near the center of the center ring and midway between the two rings.

8.6.4 Cover the soil surface within the center ring and between the two rings with splash guards (150-mm (6-in.) square pieces of burlap or rubber sheet) to prevent erosion of the soil when the initial liquid supply is poured into the rings.

8.6.5 Use a pail to fill both rings with liquid to the same desired depth in each ring. Do not record this initial volume of liquid. Remove the splash guards.

8.6.6 Start flow of fluid from the graduated cylinders or Mariotte tubes. As soon as the fluid level becomes basically constant, determine the fluid depth in the inner ring and in the annular space to the nearest 2 mm (1⁄16 in.) using a ruler or tape measure. Record these depths. If the depths between the inner ring and annular space varies more than 5 mm (1⁄4 in.), raise the depth gage, constant-level float valve, or Mariotte tube having the shallowest depth.

8.6.7 Maintain the liquid level at the selected head in both the inner ring and annular space between rings as near as possible throughout the test, to prevent flow of fluid from one ring to the other.

NOTE 7—This most likely will require either a continuing adjustment of the flow control valve on the graduated cylinder, or the use of constant-level float valves. A rapid change in temperature may eliminate use of the Mariotte tube.

8.7 *Measurements*:

8.7.1 Record the ground temperature at a depth of about 300 mm (12 in.), or at the mid-depth of the test zone.

8.7.2 Determine and record the volume of liquid that is added to maintain a constant head in the inner ring and annular space during each timing interval by measuring the change in elevation of liquid level in the appropriate graduated cylinder or Mariotte tube. Also, record the temperature of the liquid within the inner ring.

8.7.3 For average soils, record the volume of liquid used at intervals of 15 min for the first hour, 30 min for the second hour, and 60 min during the remainder of a period of at least 6 h, or until after a relatively constant rate is obtained.

8.7.4 The appropriate schedule of readings may be determined only through experience. For high-permeability materials, readings may be more frequent, while for low-permeability materials, the reading interval may be 24 h or more. In any event, the volume of liquid used in any one reading interval should not be less than approximately 25 cm^3.

8.7.5 Place the driving cap or some other covering over the rings during the intervals between liquid measurements to minimize evaporation (see 8.2.1).

8.7.6 Upon completion of the test, remove the rings from the soil, assisted by light hammering on the sides with a rubber hammer.

9. Calculations

9.1 Convert the volume of liquid used during each measured time interval into an incremental infiltration velocity for both the inner ring and annular space using the following equations:

9.1.1 For the inner ring calculate as follows:

$$V_{IR} = \Delta V_{IR}/(A_{IR}\cdot\Delta t) \tag{1}$$

where:

V_{IR} = inner ring incremental infiltration velocity, cm/h,
ΔV_{IR} = volume of liquid used during time interval to maintain constant head in the inner ring, cm^3,
A_{IR} = internal area of inner ring, cm^2, and
Δt = time interval, h.

9.1.2 For the annular space between rings calculate as follows:

$$V_A = \Delta V_A/(A_A\cdot\Delta t) \tag{2}$$

where:

V_A = annular space incremental infiltration velocity, cm/h,
ΔV_A = volume of liquid used during time interval to maintain constant head in the annular space between the rings, cm^3, and
A_A = area of annular space between the rings, cm^2.

10. Report

10.1 Report the following information in the report or field records, or both:

10.1.1 Location of test site.

10.1.2 Dates of test, start and finish.

10.1.3 Weather conditions, start to finish.

10.1.4 Name(s) of technician(s).

10.1.5 Description of test site, including boring profile, see 10.1.12.

10.1.6 Type of liquid used in the test, along with the liquid's pH. If available, a full analysis of the liquid also should be recorded.

10.1.7 Areas of rings and the annular space between rings (nearest 1 cm^2 or better).

10.1.8 Volume constants for graduated cylinders or Mariotte tubes (nearest 0.01 cm^3 or better).

10.1.9 Depth of liquid in inner ring and annular space (nearest 2 mm or better).

10.1.10 Record of ground and liquid temperatures (nearest 0.5°C), incremental volume measurements (nearest 1 cm^3 or better), and elapsed time (nearest 1 min. or better).

10.1.11 Incremental infiltration velocities (use 3 significant digits) for inner ring and annular space. The rate of the inner

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ring should be the value used if the rates for inner ring and annular space differ. The difference in rates is due to divergent flow.

10.1.12 If available, depth to the water table and a description of the soils found between the rings and the water table, or to a depth of about 1 m (3 ft).

10.1.13 A plot of the incremental infiltration rate versus total elapsed time (see Fig. 4).

10.2 An example field records form is given in Fig. 3.

10.3 See Appendix X1 for information on the determination of the moisture pattern.

11. Precision and Bias

11.1 No statement on precision and bias can be made due to the variability in soils tested and in the types of liquids that might be used in this test method. Because of the many factors related to the soils, as well as the liquids that may affect the results, the recorded infiltration rate should be considered only as an index value.

12. Keywords

12.1 coefficient of permeability; hydraulic conductivity; infiltration rate; infiltrometer; in-situ testing; Mariotte tube

APPENDIX

(Nonmandatory Information)

X1. DETERMINATION OF MOISTURE PATTERN

X1.1 Although not considered a required part of the test method, the determination of the moisture pattern in the moistened soil beneath the infiltration rings commonly provides information useful in interpreting the movement of liquid through the soil profile. For example, horizontal liquid movement may be caused by lower-permeability layers and will be identified by a lateral spreading of the wetted zone. Thus, the exploration of the soil moisture pattern below an infiltration test in an unfamiliar area may identify subsurface conditions that may have affected the test and later applications of the data.

X1.2 If the investigator wishes to make such a study, dig a trench so that one wall of the trench passes along the center line of the former position of the rings. Orient the trench so that the other wall is illuminated by the sun, if the day is sunny. If feasible, dig the trench large enough to include all of the newly moistened area. Collect samples from the shaded wall of the trench for determination of water content. If preferred, an auger, such as the orchard barrel type, may be used to determine the approximate outline of the moistened area below the rings and to collect samples for water content.

X1.3 Plot the visibly moistened area on graph paper or on the cross-section part of the report form (see Fig. 4). If samples were collected and water contents were determined, contours of water content also can be plotted on the graph.

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Attachment B. Lysimeter Installation and details.

SHORT COMMUNICATIONS

Improvements to Measuring Water Flux in the Vadose Zone

Kevin C. Masarik,* John M. Norman, Kristofor R. Brye, and John M. Baker

Abstract

Evaluating the impact of land use practices on ground water quality has been difficult because few techniques are capable of monitoring the quality and quantity of soil water flow below the root zone without disturbing the soil profile and affecting natural flow processes. A recently introduced method, known as equilibrium tension lysimetry, was a major improvement but it was not a true equilibrium since it still required manual intervention to maintain proper lysimeter suction. We addressed this issue by developing an automated equilibrium tension lysimeter (AETL) system that continuously matches lysimeter tension to soil-water matric potential of the surrounding soil. The soil-water matric potential of the bulk soil is measured with a heat-dissipation sensor, and a small DC pump is used to apply suction to a lysimeter. The improved automated approach reported here was tested in the field for a 12-mo period. Powered by a small 12-V rechargeable battery, the AETLs were able to continuously match lysimeter suction to soil-water matric potential for 2-wk periods with minimal human attention, along with the added benefit of collecting continuous soil-water matric potential data. We also demonstrated, in the laboratory, methods for continuous measurement of water depth in the AETL, a capability that quantifies drainage on a 10-min interval, making it a true water-flux meter. Equilibrium tension lysimeters have already been demonstrated to be a reliable method of measuring drainage flux, and the further improvements have created a more effective device for studying water drainage and chemical leaching through the soil matrix.

As THE NEED for quality water and nutrient management continues to grow, a better understanding of water drainage and chemical leaching through the vadose zone also is needed. Leaching can move large amounts of nutrients and other pollutants from the soil surface and root zone to the ground water (Jemison and Fox, 1994). Therefore, monitoring and measuring techniques that can determine drainage flux from undisturbed soil profiles is critical for the determination of nutrient budgets and the evaluation of land-use practices on water quality.

Various technologies exist for measuring the drainage flux through the soil matrix by intercepting water and manually or automatically sampling the accumulated volume of water. Two types of sampling equipment commonly used for this purpose are zero-tension and fixed-tension lysimeters. Both have potential problems that can cause large errors in drainage flux measurements (Radulovich and Sollins, 1987; Jemison and Fox, 1992). Zero-tension lysimeters require that soil above the collection pan be saturated before water will drain into them. During unsaturated conditions water flow will bypass a zero-tension lysimeter and underestimate actual drainage amounts (Jemison and Fox, 1992). With fixed tension a constant tension is applied to the lysimeter to remove water from the soil matrix. Fixed-tension lysimeters are often used to obtain the chemical concentration of soil solution, but no useful relationship was found between the water collected and the amount of water drainage (van der Ploeg and Beese, 1977; Angle et al., 1991).

Technology exists to sample water flux in unsaturated soil. Passive capillary samplers (PCAPS) have been used to measure water drainage (Boll et al., 1992; Knutson and Selker, 1996) and chemical leaching from the soil, and have been shown to have greater collection efficiency than zero-tension pan lysimeters (Zhu et al., 2002). Passive capillary samplers rely on the capillary potential of a fiberglass wick to apply tension and sample water drainage in unsaturated soil. The tension applied by the PCAPS is a function of the wick material, as well as the wick length and diameter, which must be carefully selected to match soil characteristics at installation sites (Boll et al., 1992). Although many studies show the effects of capillary wicks on the chemistry of the solution collected to be negligible (Holder et al., 1991; Boll et al., 1992; Knutson and Selker, 1996), issues have been raised regarding the resistance of the wick material to weathering and the suitability of PCAPS for geochemical studies of dilute soil solutions (Goyne et al., 2000). Recently, Gee et al. (2002) developed a vadose zone water fluxmeter using a PCAPS and a tipping bucket to continuously measure collected water volumes. Unfortunately, this device has a relatively small surface-sampling area (346 cm^2) and installation requires the backfilling of soil above the collection device, which is a serious flaw in many studies that require drainage from undisturbed soil profiles.

Equilibrium tension lysimeters (ETLs) were developed by Brye et al. (1999) to address the problems

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Abbreviations: AETL, automated equilibrium tension lysimeter; ETL, equilibrium tension lysimeter; HDS, heat-dissipation sensor.

associated with zero-tension lysimeters and fixed-tension lysimeters and can be installed below an intact soil profile. By adjusting lysimeter suction to match soil-water matric potential, ETLs maintain equilibrium between lysimeters and the bulk soil. In their design, heat-dissipation sensors (HDS) were used to measure the soil-water matric potential adjacent to the lysimeter. A human operator visited each ETL periodically, typically two or more times per week, and manually adjusted ETL suction to match that of the surrounding soil. Essentially this represents a frequently adjusted, fixed-tension lysimeter. Equilibrium tension lysimeters have maintained their integrity for over 8 yr at the original installation sites, demonstrating the suitability of ETLs for long-term studies. They have been used successfully to measure drainage fluxes (Brye et al., 2000) as well as nitrogen and carbon (Brye et al., 2001) and soluble phosphorus leaching (Brye et al., 2002) through the soil of prairie and corn (*Zea mays* L.) agroecosystems. Despite the improved performance over previous vadose zone samplers, ETLs are still prone to error due to fluctuations in soil-water matric potential that occur in between adjustments.

A refinement suggested by Brye et al. (1999) was to automate the vacuum controls to maintain a near-constant equilibrium with the soil. Recently, Lentz and Kincaid (2003) designed an automated system for ceramic-cup samplers to maintain equilibrium with the bulk soil. Ceramic-cup samplers were placed in the bottom of a stainless steel beaker filled with 15 to 20 cm of tamped soil and soil slurry before being pushed up into a soil-cavity ceiling to sample below an undisturbed soil column. Although laboratory experiments obtained an extraction–soil tension ratio to optimize the sampler for field soils, no attempt was made, in the field, to verify that equilibrium was maintained between the undisturbed soil and the ceramic cup in the bottom of the stainless steel beaker. Thus, even though the lysimeter tracked soil potential changes over time, there was no way to determine whether the soil potential at the top of the stainless steel beaker was near equilibrium with the bulk soil. Not only could the system chronically over- or underestimate the soil drainage, but large lags could occur between the time a drainage pulse reaches the top of the lysimeter and the lysimeter suction cup responds, leading to transient divergence of flow around the lysimeter. The system used a single vacuum source to maintain suction for 36 samplers, requiring a large network of tubing to connect individual sites to the vacuum source and a large power supply to operate.

The objective of our work was to develop and field-test a low-power, automated equilibrium tension lysimeter (AETL) to improve the response time of ETLs to soil-water matric potential fluctuations in the bulk soil and expand their use to more remote research locations. In addition, we also realized that an ETL, if it is properly controlled in true equilibrium mode, could be used as a water-flux meter if the water level inside of the lysimeter were continuously monitored. To keep up with the growing need for new technology to improve measurement and monitoring of drainage flux, we developed and tested, in the laboratory, a method for automated measurement of water level in an AETL. The level measurement device was not installed in the existing lysimeters because of the need to dig up the field site and remove lysimeters for sensor insertion, which would have disrupted the ongoing experiment.

Materials and Methods

Equilibrium Tension Lysimeters

Each AETL control system was designed to control two of the lysimeters originally constructed by Brye et al. (1999), which have collected reliable water drainage samples for eight consecutive years. The lysimeters were constructed of 1.6-mm-thick stainless steel and were 25.4 cm wide by 76.2 cm long by 15.2 cm tall. A 1-mm-thick porous stainless steel plate (0.2 μm) was welded to the top, and sidewalls that extend 2.5 cm above the porous plate were welded to the outside of the lysimeter walls. Two tubes were also welded to the pan lysimeter; one applied suction just below the bottom of the porous plate, and a second tube served as the drain for sample collection. A detailed construction diagram and installation procedure is described in Brye et al. (1999). An advantage of this design is that the porous plate on the top of the AETL makes direct contact with the undisturbed soil and is kept there by a strong spring pressure so that the AETL tension reliably represents the relevant soil-water matric potential influencing convergent or divergent flow above the lysimeter.

The system was tested on four lysimeters in two replicate plots for chisel plow and no-tillage treatments in an agroecosystem at the UW Agricultural Experiment Station in Arlington, WI. All plots were planted continuous corn rotation and were fertilized at optimum application rates.

Automated Control System

Each system was designed to control equilibrium for two pan lysimeters and a schematic of the electrical and pneumatic components is shown in Fig. 1. The AETLs were controlled by a datalogger (Model CR10X, Campbell Scientific, Logan, UT) and powered for 2-wk periods by a 12-V, 7.2 amp-hour rechargeable battery. Heat-dissipation sensors (HDS; 229-L, Campbell Scientific) connected to an excitation module (CE8; Campbell Scientific) were used to measure soil-water matric potential fluctuations in the bulk soil adjacent to each lysimeter at a depth of 1.4 m and in the soil directly above each lysimeter. The suction applied to the bottom of the porous plate was measured with a differential pressure transducer (PX170-014GV; Omega Engineering, Stamford, CT). Suction in the lysimeter was increased with a battery-operated vacuum pump (TD-2N; Brailsford and Company, Rye, NY) or decreased by bleeding lysimeter vacuum to the atmosphere, until matching was achieved between the HDS in the soil and the lysimeter. Four, 3-way, normally open, standard-mount solenoid valves fitted with 3.2-mm (1/8-in.) barb fittings (ETO-3-12 and 11752-3; Clippard Instrument Laboratory, Cincinnati, OH) were connected to the vacuum pump and pressure transducer with 3.2-mm (1/8-in.)-i.d. clear flexible PVC tubing (14-169-7A; Fisher Scientific, Pittsburgh, PA). A 12-V relay driver (A6REL-12; Campbell Scientific) in connection with the CR10X logger controlled the operation of the vacuum pump and 3-way valves. All equipment was enclosed in a 41- × 46-cm (16- × 18-in.) fiberglass enclosure (ENC 16/18; Campbell Scientific). Copper tubing (6.4-mm-o.d.) connected the vacuum line of each lysimeter to the enclosure and clear flexible PVC tubing connected the copper tubing to a 3-way

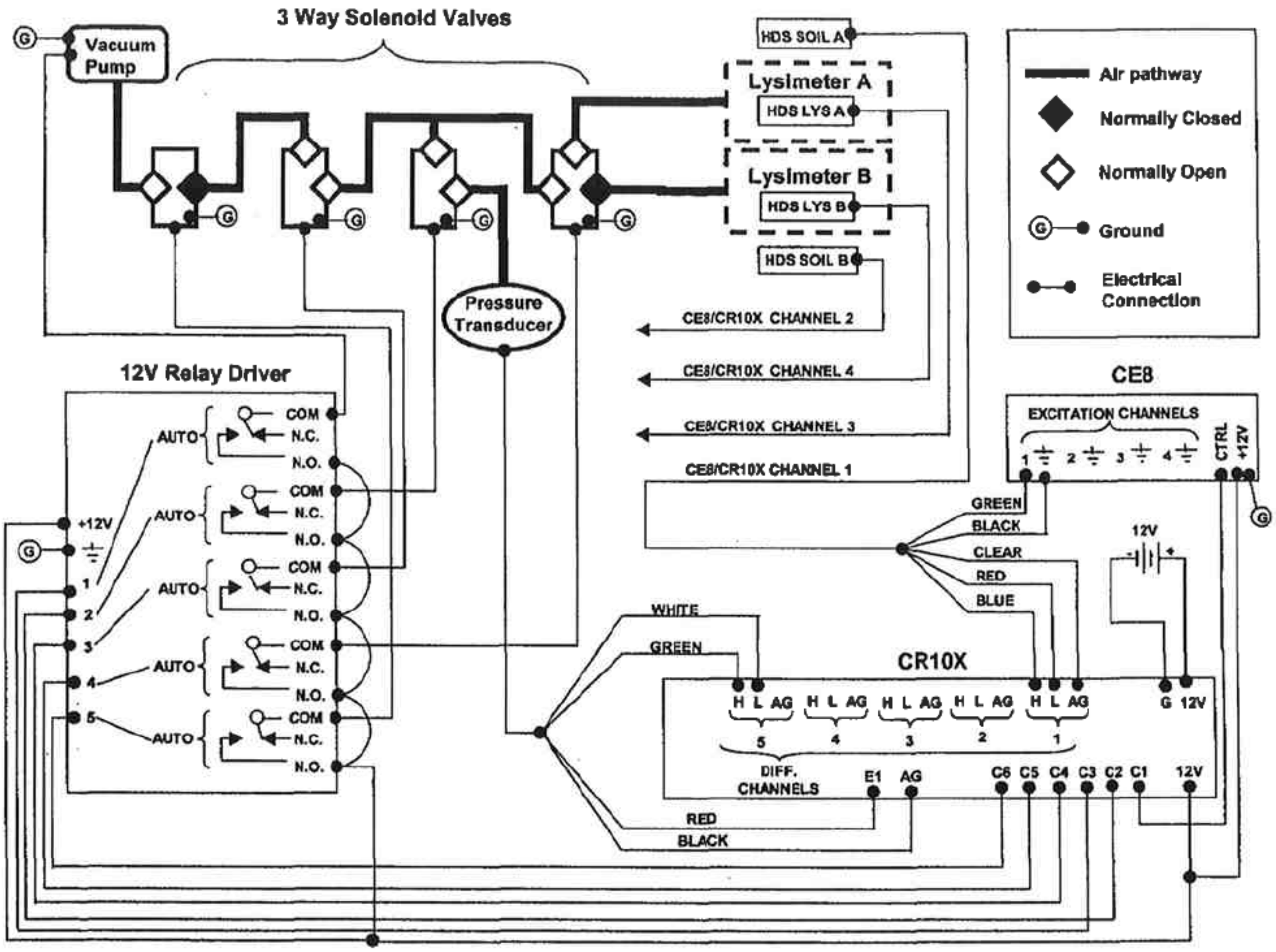

Fig. 1. Schematic diagram of an automated equilibrium tension lysimeter (AETL) system.

valve. The total cost of this control system for two AETLs, excluding the datalogger and heat-dissipation sensors, is approximately $900.

A program written for the CR10X datalogger (Masarik, 2003) maintained equilibrium for two lysimeters independently. The suction limits were set in the program to include a 2-kPa minimum and a 35-kPa maximum tension. The 2-kPa minimum was chosen because, even at saturation, a small suction must be applied before water can be pulled through the porous plate. The maximum tension of 35 kPa is just slightly below the maximum suction achievable by the vacuum pump and slightly drier than field capacity. Lysimeter suctions greater than 35 kPa cause the pump to run excessively; therefore, if the soil-water matric potential of the bulk soil measured greater than 35 kPa, no tension was applied to save battery life and prevent the lysimeter from cavitating. With a larger pump requiring three times as much power, the lysimeter could maintain equilibrium with the soil up to a suction of 60 kPa. For the soil used in this test, field capacity was reached before exceeding the 35-kPa suction, so the low-power pump was deemed sufficient.

Every 10 min the program recorded soil-water matric potentials using the HDSs for the two lysimeters (A, B) in the bulk soil and in the soil directly above the lysimeters. The soil-water matric potential measurement of sensors in the bulk soil was used to control the suction inside the lysimeter, while the HDSs above the lysimeter were used to validate the equilibrium between the lysimeters and the soil. Because HDSs operate near the voltage resolution of the dataloggers, the signals were averaged over a 10-interval period (approximately 100 min). With the recorded soil-water matric potential, the program assigns 5 min to achieve equilibrium for each lysimeter, and continues this process every 10 min until equilibrium is achieved between the lysimeter and the bulk soil. The suction inside the lysimeter is set 2 kPa greater than the soil-water matric potential of the bulk soil to overcome the resistance of the porous plate.

The control program also contained an algorithm to prevent continuous operation of the pump if cavitation of the lysimeter occurred. The arbitrarily chosen indicator for this is a continuous duty cycle for 12 consecutive 10-min execution intervals; when this occurs, the program stops controlling the lysimeter and requires human attention for manual reset. Hourly averages of the following data were stored: soil-water matric potentials for all four HDSs, Lysimeter A and B suctions, vacuum pump time for Lysimeter A and B, and battery voltage.

Water drainage was collected throughout the year since the lysimeters were located below the frost layer in the soil. Lysimeters were sampled approximately once every 14 d for the majority of the year and once every 30 d during periods when the soil surface was frozen. During sampling the program operation was suspended while the leachate was collected from the pan lysimeter. The first liter of leachate was collected for chemical analysis, while any remaining volume was measured and discarded (Brye et al., 1999).

Heat-Dissipation Sensors

The ability of the AETL to maintain equilibrium with the soil is dependent on accurate soil-water matric potential measurements. Therefore, an accurate calibration of the HDSs is critical to maintaining equilibrium of the AETLs. Each HDS's individual response curve was determined to ensure accurate measurements when placed in the field. The air-dry value was obtained by measuring the response of the sensor when it was dry and suspended in air, while the saturated value was obtained after soaking the sensors in water overnight. It is important to note that vacuum saturation was not used in calibrating these sensors because sensors did not return to vacuum saturation values after a drying cycle. Because water drainage is minimal when soils are below field capacity and tension was not applied when the soil-water matric potential measured less than −35 kPa, the most critical part of the HDS calibration was near saturation. A pressure plate was used to force water out of sensors placed in a silty-clay-loam slurry (same soil as field installation) at pressures of 5, 10, 20, 30, 40, 50, and 100 kPa. Sensors were allowed to equilibrate at each pressure and measurements were obtained using a Campbell Scientific datalogger (Reece, 1996; J. Bilskie, personal communication, 2001). Heat-dissipation sensors were excited with electrical current for a period of 10 s and the difference in temperature of the thermocouple inside of the ceramic cylinder before and after heating was recorded. A linear calibration equation was determined by plotting the natural logarithm of the calibration tensions (kPa) against the measured temperature (°C) difference (Campbell Scientific, 1998). The logarithmic relation between tension and temperature differential held for all sensors to a tension of at least 100 kPa. However, for some sensors the linear relation did not fit the 10-MPa point for the air-dry temperature difference as suggested by Reece (1996); as a result, the calibration may lose accuracy when measuring tensions above 100 kPa and can only be considered as semiquantitative measurement at tensions greater than 100 kPa. On each calibration curve sensors at saturation appeared to have a temperature difference consistent with a 5-kPa tension, which may be the air-entry value of the ceramic. One remarkable observation related to the calibration stability of the HDSs was the agreement within a few kPa of the HDS above the lysimeter and the lysimeter suction, suggesting that the calibrations on the HDSs have been stable during 8 yr of continuous use.

Water Level Detection

A wide range of options were available for measuring liquid level. We chose to test a sensor that probably would already be in use at locations where AETLs might be deployed. A new and inexpensive soil moisture gauge was chosen that measures in the frequency domain (ECH_2O probe; Decagon Devices, Pullman, WA). It requires little power and can be read directly using a CR10X datalogger. It was installed in an open-top lysimeter, diagonally from the upper front of the lysimeter internal cavity, just below the level at which the porous surface would be attached, to the lower rear of the cavity across the width of the lysimeter. Diagonal rather than vertical orientation was used to maximize the depth resolution of the measurement. For testing purposes the top was left off of the lysimeter. Water was added incrementally, and the water depth was measured with a measuring tape while the datalogger collected data from the ECH_2O probe.

Results and Discussion

Automated Equilibrium Tension Lysimeters

To test the AETL system under field conditions, two control systems were connected to four existing ETLs. Appropriate installation of ETLs, described in detail by Brye et al. (1999), is nontrivial and is critical to their subsequent performance. The ETLs were connected to the AETL pneumatic and control circuits and the system was operated from 8 Aug. 2001 to 31 Dec. 2002. The datalogger used to operate the AETL also recorded soil-water matric potentials, lysimeter suctions, and leachate volumes. A weather station was also installed nearby to record hourly climatic data.

Hourly averages of the soil-water matric potentials and the lysimeter suction for a 9-d period are shown in Fig. 2. The graph shows the response of soil-water matric potential above the lysimeter to the lysimeter suction, which was applied to match that of the bulk soil. The soil-water matric potential above the lysimeter decreased as the soil-water matric potential of the bulk soil decreased, verifying the operation of the lysimeter control system. The soil-water matric potential above the lysimeter measured slightly less than the soil-water matric potential in the bulk soil due to the 2 kPa of excess suction applied to the lysimeter.

The daily cycling of soil-water matric potential, which is closely followed by the lysimeter control system, is believed to arise from temperature sensitivity of the datalogger, which is within manufacturer specifications. Logger noise levels limit the resolution of HDSs, with 0.4-μV changes causing 10% uncertainty in recorded-tension estimates. Loggers with better voltage resolution would reduce this uncertainty, but averaging also helped to reduce its impact.

The soil-water matric potential of the bulk soil and daily precipitation amounts, along with cumulative drainage collected from the lysimeters and cumulative precipitation, are shown in Fig. 3. The soil-water matric potential measurements show the response of the bulk

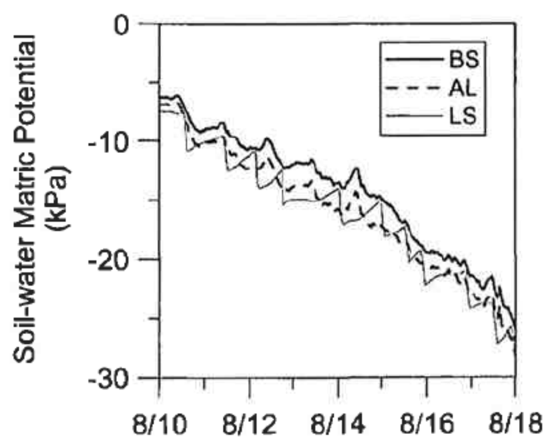

Fig. 2. Hourly response of the automated equilibrium tension lysimeter (AETL) system to changes in soil-water matric potential of the bulk soil (BS), above the lysimeter (AL), and of the lysimeter suction (LS).

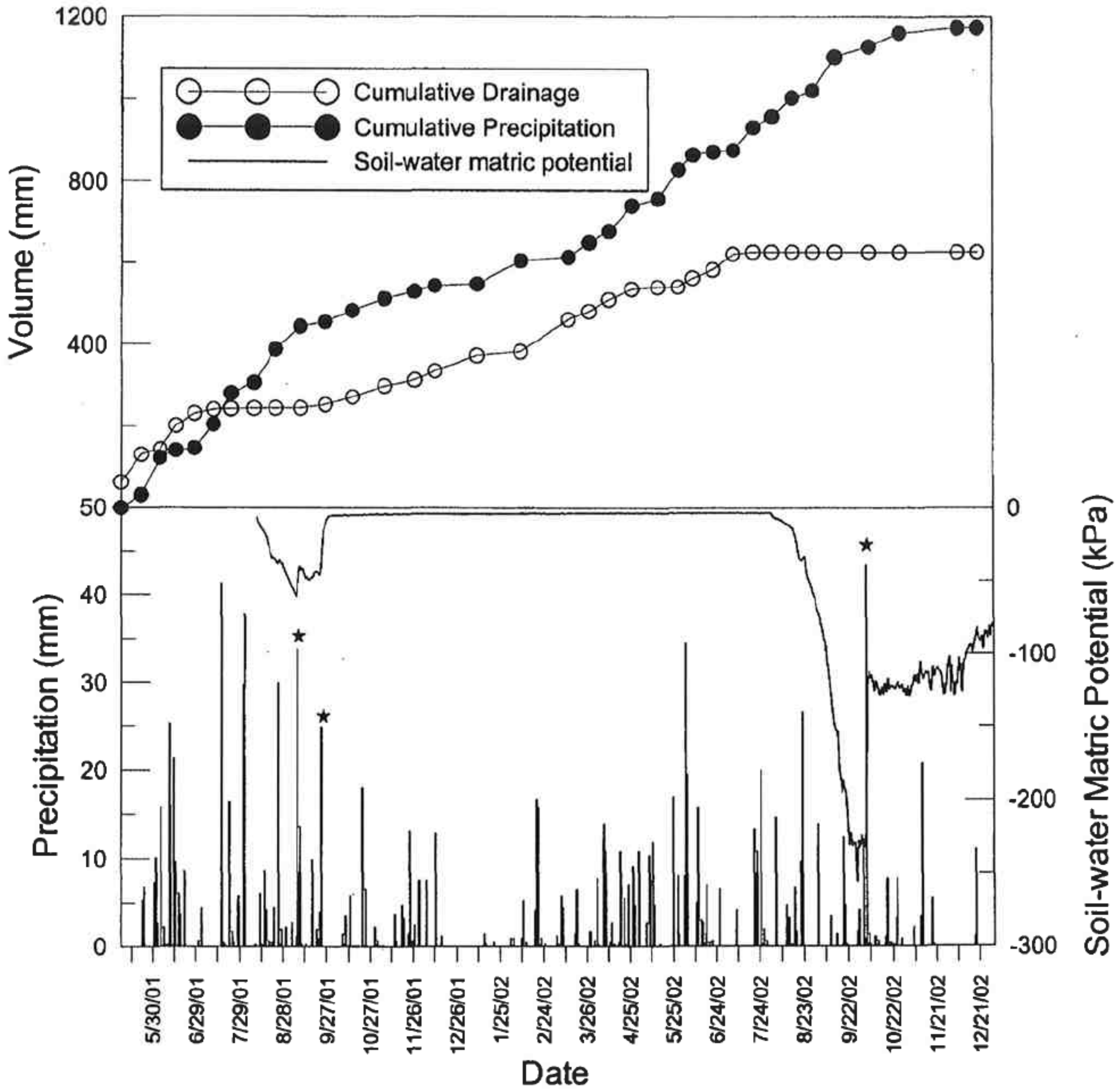

Fig. 3. Natural variation of the bulk soil suction (kPa) along with daily precipitation (mm) and leachate volumes collected (mm) at each sample date. The stars represent precipitation events that resulted in sudden increases of soil-water matric potential.

soil to the conditions experienced within the corn agroecosystem. During the summer little drainage occurred because of the high evapotranspiration rates of the corn crop, which usually exceed the amount of precipitation during the growing season. It is generally during this time when the soil-water matric potential decreased below −35 kPa and the program stops the operation of the vacuum pump; however, data collection continued as normal. The program automatically reactivated the pump operation anytime the soil-water matric potential increased above −35 kPa. As the corn matured and evapotranspiration rates increased, the amount of water within the soil matrix decreased. The corresponding decrease in soil-water matric potential is evident during both growing seasons, in particular during 2002 from 15 August to 10 October when it reached a low of −230 kPa. The total precipitation from May to October was 503 mm in 2001 compared with only 356 mm in 2002, which may explain the nearly 200-kPa-lower minimum soil water matric potentials for the 2002 growing season. Since precipitation in 2002 was less than in 2001, the water demand of the crop was met by removing more of the water stored within the soil.

Shortly after the major precipitation event on 10 Oct. 2002, the soil-water matric potential increased by 100 kPa, verifying the movement of water downward through

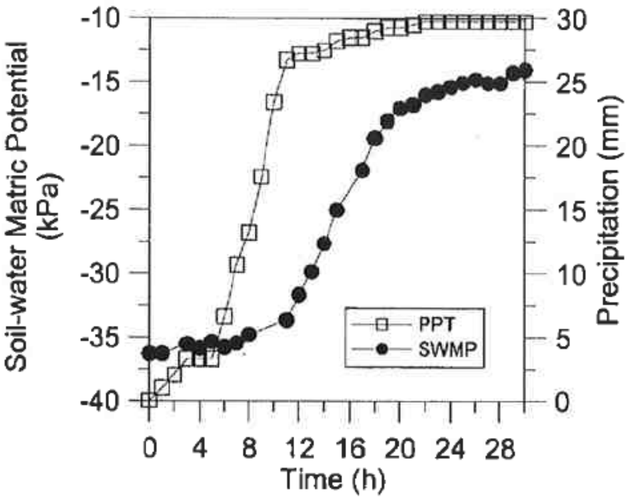

Fig. 4. Hourly measurement of soil-water matric potential and cumulative precipitation (PPT) following the rainfall event on 24 Sept. 2001.

the soil matrix. Sudden increases in soil water content also occurred within the same day of major precipitation events on 7 and 24 Sept. 2001. Figure 4 shows that an increase of soil-water matric potential at a depth of 1.4 m was recorded within hours of the peak of the precipitation event and steadily increased over the next 20 h. These sudden increases in water content observed after major precipitation events indicate macropore flow for which previous manual adjustment of ETLs could not properly account.

Following the rainfall of 24 Sept. 2001 the soil-water matric potential increased and remained nearly constant at −5 kPa until the following summer. This increase in soil-water content, which was also observed in 2002, is indicative of the decrease in evapotranspiration due to crop senescence and seasonal climatic changes. Following the end of the growing season, precipitation begins to replace the water within the soil matrix that was removed by the corn plants. Because of the below normal precipitation and large amount of water removed during the 2002 growing season, the soil still had not reached field capacity as of 31 Dec. 2002. Periods with soil-water matric potential below field capacity (−30 kPa) resulted in little to no leachate being collected. As a result no drainage occurred from July 2002 to December 2002 since the soil above the lysimeter was drier than field capacity.

A comparison was performed using data collected from the original ETLs designed by Brye et al. (1999) and the automated design. Results in Table 1 compare the variability of sampling methods using data collected during years with similar precipitation patterns. Similar precipitation patterns result in similar patterns of collected drainage volumes and drainage variability from the mean for the two periods should also be similar if the manual adjustment and automated control systems are equivalent. Two periods were chosen in which precipitation events of varying degrees of magnitude occurred with similar frequency. Precipitation events during the growing season were not considered when choosing periods, because very little drainage occurs during this period due to evapotranspiration. Results indicated that the variability from the mean of the new system to maintain equilibrium and measure leachate volumes was comparable with that of the original ETL system.

Water Level Detection

The results of the water level detection tests are shown in Fig. 5. The ECH_2O probe displayed reliable results and has the added advantage of simplicity in operation and a low power requirement. The probe data can be fit to any of a number of calibration functions; the one shown has a standard error of estimate of 0.35 mm (R^2 = 0.998). Inclusion of this probe in future AETLs will provide a continuous measurement of water depth, creating a water-flux meter with sub-mm scale resolution of drainage and also making it possible to determine macropore flow rates in the field.

Conclusions

The development of an automated equilibrium tension lysimeter has successfully expanded the existing capabilities of ETLs. Without the need for a large power supply, AETLs can now be used in remote research locations. More importantly, the automatic adjustment of the lysimeter tension enables a near-constant equilibrium to be maintained between the lysimeter and the soil, providing a more accurate collection of water drainage over other drainage sampling devices. The AETL also has the added advantage of measuring soil-water matric potentials to monitor when wetting and drying periods occur within the soil. The ability to monitor soil-water matric potential adds validity to drainage measurements and can be used to interpret drainage variations below the root zone. Demonstration of the ability to measure the level of water within the lysimeter repre-

Table 1. Comparison of leachate volume variation collected from replicate lysimeters in two tillage treatments using the original equilibrium tension lysimeter (ETL) system and the new automated (AETL) system during periods with similar precipitation patterns.

				Leachate volumes‡			
				Chisel plow		No tillage	
	Collection period	Total precipitation	n†	Rep 1	Rep 2	Rep 1	Rep 2
		mm		mm			
Original	1 Oct. 1996–30 Sept. 1997	744	23	13.9 (0.9)	21.5 (1.1)	13.0 (1.1)	9.8 (1.3)*
New	1 Oct. 2001–30 Sept. 2002	603	22	16.6 (1.1)	17.4 (1.1)	16.3 (0.9)	10.0 (0.8)

* Significant at the 0.05 probability level.
† Number of times the lysimeters were sampled.
‡ Values are means with coefficients of variation in parentheses.

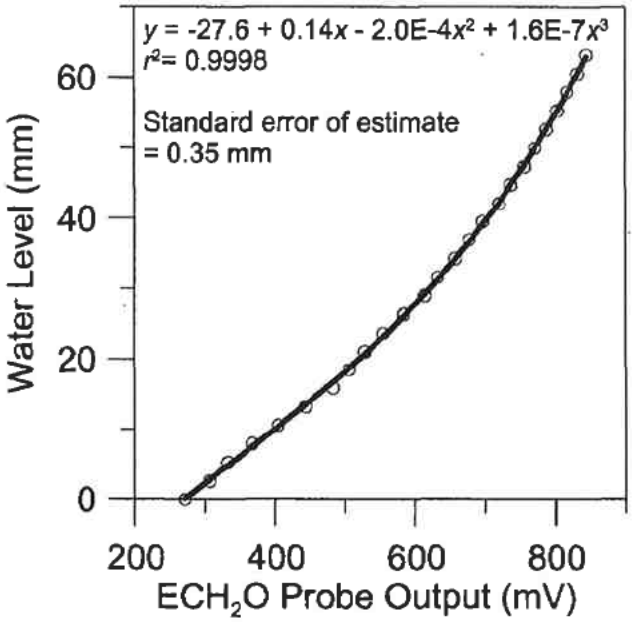

Fig. 5. Water level versus ECH_2O probe output. The ECH_2O probe was measured by a datalogger after each increment of water was added and water level was confirmed with manual measurement.

sents a further advancement in vadose zone measurement and monitoring, which makes AETLs true water-flux meters and allows temporal resolution of unsaturated drainage that was never before possible.

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Consent Decree—Attachment B

Priest Lake Dam Reconstruction Project

Location

Priest Lake recreation site is located about 13 miles south of Telluride, Colorado, and approximately 0.6 miles upstream of the Matterhorn Campground. This site consists of five-acre Priest Lake, one restroom, and an undefined and unpaved parking area. It is about 0.5 miles off State Highway 145, near Lizard Head Pass.

Site Information and Background

Priest Lake was originally constructed by enlarging a small natural lake in 1953, perhaps as early as 1940, by a private landowner. The lake was enlarged in 1952 to its current size with a structural height of 14 feet and hydraulic height of 11 feet and a storage capacity of 113.8 acre-feet. The crest of the dam was approximately 420 feet long with a crest width of approximately 12 feet before it was breached. It was a high hazard dam because camp sites below would be inundated by an intense storm event causing the dam to fail or overtop. In 2003, the Forest Service made the decision to breach the dam due to excessive leakage and stability concerns and its classification as high-hazard. The dam was breached during the summer of 2004, resulting in a significant drop in the water level and loss of public and private fishing opportunities. With the breach, the resulting dam hazard classification was reduced to low. The Forest Service has always desired rebuilding Priest Lake dam to supply augmentation water for depletions associated with the Matterhorn Campground and guard station. Since the breaching the FS has leased water from Trout Lake for this purpose. The Forest Service also has an interest along with Colorado Parks and Wildlife to return the recreational value of the lake by providing public angling opportunity.

Current Conditions:

The U.S. Forest Service owns the lake and senior water rights for both storage and augmentation. Priest Lake has water rights completed appropriation for 52.2 acre-feet of water storage in Priest Lake (58.3 acre-feet of dead storage) to be used for domestic, 12 acres of irrigation, and augmentation. The FS needs 1.02 ac-ft for augmenting Matterhorn Campground and Administrative Site usage. Currently the Priest Lake dam is breached due to recurring piping problems of the high hazard dam.

Recreation and Existing Uses

The lake was a popular recreation area and was the main attraction for users of the area. Historically, most summer recreation use at Priest Lake has been associated with day-use fishing that occurs from about June through October. Dispersed, no-fee camping was also popular with users, with the heaviest use taking place during summer festivals and holiday weekends. Two fly-fishing companies and a local children's summer camp are authorized to conduct fishing and boating activities at the reservoir. During the winter months, the Telluride Nordic Association is authorized to groom cross-country ski trails around the lake. The existing small lake provides limited recreational use but the fishery is very limited and angling use is currently low.

Potential Conservation Value

Colorado Parks and Wildlife (CPW) along with the Forest Service would like to establish a self sustaining population of Colorado River cutthroat trout in Priest Lake, thereby returning the only native salmonid fish to former habitat. Cutthroat trout have declined drastically across their range and currently occupy only about 16% of their historic habitat. The Dolores River basin is in especially poor shape and supports fewer occupied stream miles than most other river basins across the range. Because non-native trout species compete with and hybridize with cutthroat trout, the only way to establish viable and secure populations is to isolate them from non-native trout species. Sites like Priest Lake are ideal places to restore native fish where a reservoir can prevent the upstream migration of non-native brook trout. The current size of the lake is too small to provide enough permanent habitat to support a viable population of cutthroats and CPW would like to see the lake enlarged to its previous size. Then a local population of cutthroat trout that are native to the San Miguel basin could be translocated into the lake to establish a new conservation population of native fish.

Project Status

The Forest Service has considered making a small enlargement of the lake just to be able to provide augmentation water. This would involve building a small 2-foot impoundment with a 12-inch gate or stop log outlet works to allow for downstream releases. The small dam would cost between $60,000 and $80,000 to construct using the BOR construction crew. A dam hazard analysis program was performed modeling severe storm events through this sized structure. This small 2-foot dam would not be considered high hazard, however it would not function as any more than an augmentation feature for our small water uses. This would only slightly enlarge the lake and would not provide enough aquatic habitat to support a recreational fishery or a cutthroat population.

Recently, a new dam hazard analysis has indicated that there is little value in attempting to keep the hazard classification lower by reducing its original height. Increasing the dam height enough to store even only half the original storage amount did not change its classification. This size dam would also be classified high hazard. The limiting factor in resizing the dam to reduce its hazard classification is the culvert in the roadway across from the camp ground. This culvert would have to be replaced by a significant length bridge to allow the flow of flood waters down the nearby drainage. If left as it is, the culvert impounds the flood waters to back up into the camp ground.

The main recommendation from the hazard analysis is to ensure the rebuilt dam is properly designed and constructed to prevent piping or leaking and reduce risk of failure in a large flood event. The spillway is designed to pass the 100-year storm. If the dam remains intact during a flood event then less water is going to be backed up at the downstream culvert. All of the interested parties have agreed that the best solution is to explore rebuilding Priest Lake to its former size with modern specifications.

This project has recently been estimated by the Bureau of Reclamation (BOR) to cost about $1.1 million. The estimate includes removing the dam to its foundation and removing and replacing the organic material it was built on with suitable material. Then the original dam would be reconstructed using existing material and a liner installed on the upstream face. An outlet and a toe drain with a filter would also be installed. We feel it would not be a large expense to create a spawning channel and fish barrier downstream of the existing dam. This would meet FS recreation, augmentation, and fishery needs, and present the possibility, if allowed by the Agency, to lease FS water rights for other entities' augmentation needs keeping in mind the fishery needs.

The U.S. Forest Service is a strong proponent of the project but securing that level of funding in the current economic environment is unlikely. CPW also strongly supports the project and the agencies are looking for partners in this effort, especially a non-governmental entity to spearhead fundraising for the project. There are many grant opportunities in both state and federal government that are likely sources of funding for a project with so many recreational and conservation benefits, but financial partners must be identified to assist in funding the project.

Native Colorado River Cutthroat Trout in Spawning Colors.