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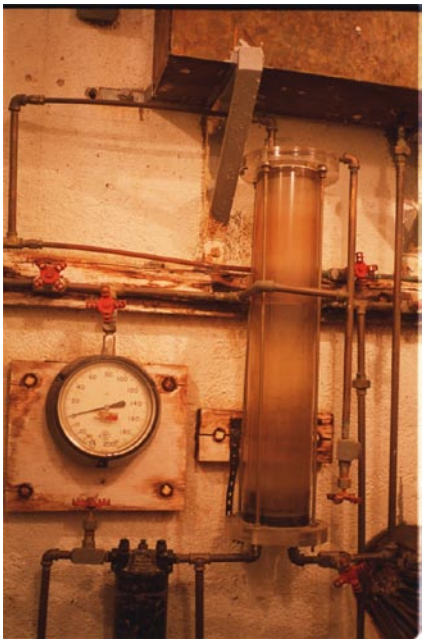
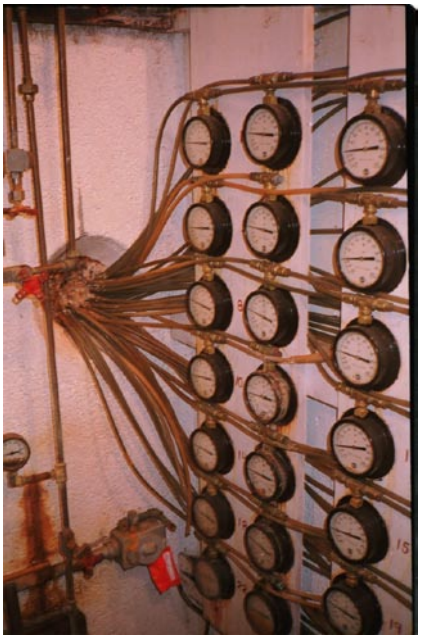
Operations and Maintenance Guidelines for Hydraulic Piezometer Installations at Dams





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Operations and Maintenance Guidelines for Hydraulic Piezometer Installations at Dams

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Operations and Maintenance Guidelines for Hydraulic Piezometer Installations at Dams

I. Executive Summary

This document provides guidance concerning hydraulic piezometer installations relative to the requirements and responsibilities indicated in Directive FAC 01-08, Dam Safety Performance Monitoring for High- and Significant-Hazard Dams, and as indicated in Policy Directive FAC P02, Decisions Related to Dam Safety Issues.

Hydraulic piezometer systems have been installed in 50 Reclamation embankment dams. They consist of piezometers installed in the dam embankment or foundation, tubing running from the water-filled chambers of the piezometers to "separate gauges" in a terminal well, and ancillary equipment in the terminal well that allows flushing of the tubing and accuracy checks to be made of the separate gauges.

A hydraulic piezometer terminal well is classified as a “confined space,” and may be a “permit-required confined space," as determined on a case-by-case evaluation of the specific hazards and circumstances. Confined spaces, including permit-required confined spaces, are addressed in Section 14 of the Reclamation Safety and Health Standard. The applicable OSHA regulations associated with entering and working in a permit-required confined space are detailed in 29 CFR 1910.146, which can be viewed at www.osha.gov.

The conditions in every hydraulic piezometer terminal well, whether active or abandoned, should be periodically checked for seepage at the tube bundle entrance location in the terminal well and for breaks or leaks in piezometer lines and other hydraulic piping within the hydraulic piezometer terminal well. If either of these conditions is present, they could possibly lead to development of a seepage-related failure mode, and therefore need to be promptly and appropriately addressed.

The intent of the annual maintenance work, which includes flushing the piezometer tubing and checking the validity of each of the separate gauges, is as follows:

1. Eliminate air from within the piezometer tubing, which, if present, would lead to inaccurate data.

2. Flush out bacterial material from within the piezometer tubing, which, if left unchecked, could grow and potentially plug off the tubing such that the instrument would eventually need to be abandoned.

3. For each individual separate gauge, obtain a reading of it at the same time a "master gauge" reading is taken, with the same pressurized water acting on both gauges so that it can be determined if the separate gauge is functioning satisfactorily or if it needs to be replaced.

4. Based on the work and results of item 3 above, a “separate gauge correction amount” can be developed for each separate gauge so that readings from it can be adjusted to the "most probable value," using all the information available from the master gauge work performed. This adjustment is to account for gauges that historically read a little high or low.

5. Gather important "performance" information about each piezometer installation, learned during the flushing work, and document it for future reference. Typically the information relates to water lost (or gained) during flushing and debris and/or air observed at the air trap during flushing. Sometimes, however, more unusual performance takes place during flushing and it is very valuable to document what is observed so that appropriate actions can be taken regarding the piezometer in the future.

An "Annual Maintenance Report Form" (AMRF) has been developed to capture all the key data and information obtained in the course of the annual maintenance work. Copies of this form, customized for the dam where it will be used, are available from D-8460. An example blank AMRF is provided in Appendix F, and an example completed AMRF is provided in Appendix G.

Obtaining routine readings at standard Reclamation hydraulic piezometer installations simply involves reading and recording the indicated pressures on the separate gauges. Since there are two separate gauges for each piezometer, one on each of the two lines of tubing running to the terminal well, redundant data are collected that allow an immediate check on the data for apparent validity. When separate gauge readings for a piezometer are entered into the Reclamation Instrumentation Computer Database, called DAMS (Data Acquisition and Management System), DAMS will automatically compute a piezometric water level, if the data appear to be valid (the separate gauge readings agree sufficiently). If the data do not appear to be valid, the data entry program will accept the raw readings and store them, but will not compute and store a water level using the suspect data. Instead, the program will indicate that raw reading data appear to be invalid. Investigation of the problem should be promptly initiated.

For separate gauge data that appear to be valid, the piezometric water surface elevation (in feet) for the piezometer is determined by the DAMS system using the following process:

1. Each "raw" separate gauge reading is adjusted using the applicable "separate gauge correction amount" developed from master gauge data.

2. The two adjusted separate gauge readings associated with each piezometer are averaged, the tip elevation is added to this average value, and a correction factor (the tip constant) is added to or subtracted from this value to account for the elevation difference between the piezometer tip and the separate gauges for the instrument.

Whenever an Annual Inspection, Periodic Facility Review (PFR), or Comprehensive Facility Review (CFR) inspection of the dam is performed, the inspection should include inspecting the hydraulic piezometer terminal well for:

- Conditions that possibly could relate to development of a seepage-related failure mode (noted previously)

- O&M (operations and maintenance) issues, including the condition and performance of the ventilating equipment and the sump pump (if present), the degree of vandalism protection provided by the access door and door lock, the condition of the frost floor, the provisions for personnel safety (e.g. “ladder-up” provided?), whether conditions are sanitary (e.g. mice in well can result in hantavirus), and general equipment maintenance and upkeep matters.

Personnel from D-8460 are available to provide assistance in obtaining equipment and/or performing the actual repair/replacement work relative to hydraulic piezometer installations. Some of the specialized equipment needed for hydraulic piezometer installations (for instance the air trap, the bypass relief valve for the pumps, and the pressure check valves for the pump circuit and master gauge) should only be ordered by D-8460, because of the nature of the equipment.

The determination to abandon a hydraulic piezometer terminal well should only be made at the time a CFR is performed relative to the dam. The CFR process includes a formal evaluation of the dam's current dam safety performance monitoring needs, involving TSC, regional office and area office personnel, and as such represents the right forum for determining appropriate changes to the monitoring program. No grouting of hydraulic tubing or backfilling of terminal wells should be performed relative to abandoned installations, unless a specific recommendation is made to perform this work.

II. Overview and General Information

Hydraulic piezometer systems have been installed in 50 Reclamation embankment dams. These water pressure monitoring systems are simple in concept, which is a very attractive attribute, but require rather involved maintenance to be performed

annually. Hydraulic piezometers are installed in the embankment or foundation of a dam, in a location where collection of water pressure data is desired. Figure 1 shows a typical piezometer used in the embankment of a dam, while Figure 2 shows a piezometer that can be lowered into a drill hole to monitor foundation pressures. The piezometer consists of a water-filled chamber that has one or two filter disks that allow the external water pressure to be transmitted to the water within the piezometer, but prevent movement of soil into the piezometer. Two water-filled tubes run from the water-filled chamber of the piezometer to Bourdon-type pressure gauges located in a terminal well at the downstream toe of the dam. Figure 3 shows a typical arrangement of piezometers in a cross section through a dam, the associated tubing, and the terminal well located at the downstream toe of the dam. For most Reclamation dams having hydraulic piezometers, there is only one terminal well and array of associated instruments, which are typically at or near the maximum section of the dam. However, some dams have more than one instrumented section.

Hydraulic piezometer systems allow piezometric water surface elevations to be determined at each piezometer by reading the two "separate" pressure gauges associated with each instrument, and then applying instrument-specific correction factors and constants. Since there are two separate gauges for each piezometer, one on each of the two lines of tubing, redundant data are collected that allow an immediate check on the quality of the data. The "twin tubes" of each piezometer also allow water to be circulated through the tubing to remove any air in the lines (which would lead to inaccurate data) and to remove bacterial growth (that could eventually plug off the lines if maintenance was neglected). The terminal well contains a water filter, an air trap, valving, and a pump (typically an electric pump) which allows flushing of the lines (which should be done at least annually). The terminal well also has a "master gauge" to allow checking of the accuracy of each of the separate gauges installed in association with the individual piezometers, and the development of correction factors that need to be applied to the raw separate gauge readings. Similar to flushing work, master gauge readings should also be carried out at least annually. If any of the separate gauges reads a negative pressure, a hand pump will be needed in the well for setting a negative pressure during the master gauge reading process. Figures 4 and 5 show photographs of separate gauges and other equipment in a hydraulic piezometer terminal well, while Figures 6, 7, and 8 show schematic views of the equipment and tubing in terminal wells constructed based on Drawing Nos. 40-D-4554, -4664, and -6088, respectively.

Since hydraulic piezometer tubing runs in an upstream/downstream direction to the downstream toe of the dam, in some instances from areas near or even upstream of the upstream edge of the dam's core material, the presence of the tubing creates the potential for seepage-related problems. Poor special compaction of material placed adjacent to the tubing or in the tubing trenches could create relatively pervious seepage paths through the dam. Tubing breaks could cause

water under high pressure to be injected into the downstream portions of the dam. Other possibilities exist as well. Consequently, monitoring needs to be routinely performed to check for evidence of possible dam safety problems associated with the hydraulic piezometer systems.

Major work activities associated with hydraulic piezometer installations are as follows:

1. Routine monitoring of conditions in hydraulic piezometer terminal wells.

2. Routine reading of hydraulic piezometers.

3. Annual maintenance of hydraulic piezometer installations, including flushing the lines and obtaining master gauge readings.

4. Processing and evaluation of hydraulic piezometer data.

5. Formal inspection of hydraulic piezometer installations, during an Annual Inspection, Periodic Facility Review (PFR), or Comprehensive Facility Review (CFR).

6. Repair or replacement of hydraulic piezometer system components.

7. Abandonment of hydraulic piezometer systems.

Each of these seven topics will be discussed in the remaining sections of these guidelines, after first discussing safe entry into hydraulic piezometer terminal wells. For every dam having hydraulic piezometer installations, complete guidance concerning all needed O&M work for these installations should be provided in the SOP. Whenever O&M work is performed relative to hydraulic piezometer installations, or whenever there are noteworthy occurrences or developments regarding these installations, appropriate logbook entries need to be made to document the situation.

These guidelines provide information concerning hydraulic piezometer installations relative to the requirements and responsibilities indicated in Directive FAC 01-08, Dam Safety Performance Monitoring for High- and Significant-Hazard Dams, and as indicated in Policy Directive FAC P02, Decisions Related to Dam Safety Issues.

III. Safe Entry Into Hydraulic Piezometer Terminal Wells

A. General Overview

There is no work that needs to be done in a hydraulic piezometer terminal well

that would ever justify taking shortcuts or making compromises that could potentially affect the safety of the worker(s) involved.

Because a hydraulic piezometer terminal well has limited and restricted means for entry and exit, and because it is not designed for continuous employee occupancy, it is classified as a "confined space." A "permit-required confined space" means a confined space has one or more of the following characteristics:

1. Contains or has a potential to contain a hazardous atmosphere;

2. Contains a material that has the potential for engulfment of an entrant;

3. Has an internal configuration such that an entrant could be trapped or asphyxiated by inwardly converging walls or by a floor which slopes downward and tapers to a smaller cross-section; or

4. Contains any other recognized serious safety or health hazard.

A decision as to whether a particular hydraulic piezometer terminal well represents a "permit-required confined space" needs to be made on a case-by-case basis. Confined spaces, including permit-required confined spaces, are addressed in Section 14 of the Reclamation Safety and Health Standard, which is accessible via Reclamation's intranet. The applicable OSHA regulations associated with entering and working in a permit-required confined space are detailed in 29 CFR 1910.146, which can be viewed at www.osha.gov (look up "Standards (29 CFR)" in the "Site Index," then access Part 1910, and then access Part 1910.146).

Besides "confined space" considerations, a number of other safety issues need to be addressed in the job hazard analysis relative to entering and working in a hydraulic piezometer terminal well.

B. Detailed Discussion

There are two special concerns relative to entering a hydraulic piezometer terminal well that relate to the quality of the air that could be present: (a) an oxygen deficiency could exist, and (b) dangerous gases or vapors may be present. If a person loses consciousness in the well due to either of these circumstances, not only is that person in a life-threatening situation, but anyone entering the well trying to save the person similarly could lose consciousness (for the same reason) and could also be imperiled. Consequently, if there is a risk that circumstances could develop that could cause someone to lose consciousness in the well, then people should only enter the well if they are in a body harness and are accompanied by a person at the ground surface who has hoisting equipment attached to the harness that is sufficient to lift the person out of the well in the event a problem develops.

Other necessary risk mitigation measures associated with the "air-related" safety problem in a terminal well include the following:

1. Running ventilation equipment provided for the terminal well for a significant time period (at least 30 minutes) before anyone enters the well, and continuing to run the equipment while people are in the well. Most hydraulic piezometer terminal wells are equipped with appropriate ventilation equipment. Those that are not should promptly get the equipment, and comparable, portable ventilation equipment should be used in the interim.

2. Using air monitoring equipment to check the air quality in the well before anyone enters it. Obviously the air monitoring equipment needs to be reliable (including appropriately calibrated and tested prior to use) and must be capable of providing information concerning oxygen levels and the particular dangerous gases or vapors that might be present at the well it is to be used in. These gases or vapors could include hydrogen sulfide (H_2S), chlorine (Cl_2), carbon monoxide (CO), and sulfur dioxide (SO_2), as well as combustible gases.

3. Wearing appropriate air monitoring equipment while within the well, and immediately exiting the well should the equipment detect an air quality problem.

4. Being aware of the history of any air-related problems in the well. Of particular concern would be any instances where the air quality in the well changed in a fairly rapid way from a satisfactory condition to an unsatisfactory condition. If there has ever been an instance where an air monitor registered an unsatisfactory condition in a particular terminal well, then that terminal well needs to be treated as a “permit-required confined space” in the future.

If good safety procedures are routinely carried out (items 1, 2, and 3 above), and if there is no history of air-related problems (pertains to item 4 above), then the use of a body harness and hoisting equipment will probably not be necessary in most instances. In lieu of using a body harness and hoisting equipment, one of the following alternative approaches should be employed (in addition to satisfying the requirements stated in items 1, 2, 3, and 4 above):

1. Having a person at the ground surface monitoring the situation in the well while someone is in the well.

2. Having the person who is going into the well: (a) inform others of the planned activity, including when it is expected well entry and exit will occur, and (b) maintain regular radio or telephone contact with others (at agreed contact times) to ensure that all is going okay. Obviously if the agreed communication does not occur and the worker in the well is not responding to communication attempts, a rapid emergency response to the well will be necessary.

The second approach noted above would only normally be appropriate relative to obtaining routine gauge readings for the hydraulic piezometers. If the work is more involved than that, such as performing annual maintenance work (i.e. flushing the system, obtaining master gauge readings, etc.) or performing repair or rehabilitation work, then it would not be appropriate for someone to perform this work alone.

Supervisory personnel will need to determine what measures should be employed to ensure safe working conditions on a case-by-case basis. A specific permit, prepared by supervisory personnel, is required to ensure all appropriate safety measures are taken relative to working in a terminal well that is classified as a "permit-required confined space."

People that work in confined spaces, and their supervisors, need to receive training on the subject at least annually, and certification of this training is necessary prior to entering a confined space.

In addition to air quality concerns, other safety issues relative to entering and working in a hydraulic piezometer terminal well include:

1. The possibility that poisonous creatures could be present in the well.

2. The possibility that hantavirus could be present in the well, due to mice getting into the well.

3. The dangers associated with descending or ascending significant vertical distances on ladder rungs. (The condition of the ladder rungs is obviously important, and "ladder-ups" and/or additional rungs should be added where appropriate to improve safety.)

4. The dangers associated with moving around and working in a small, tightly confined work area.

5. The possibility that the frost floor could be structurally unsound (most likely due to rotting of wood) which could lead to a fall down the well from the level of the frost floor.

A job hazard analysis needs to be prepared that addresses all the potential safety concerns of the situation, including those noted above.

C. Technical Comment

It is very important that the requirements for using air monitoring equipment are strictly adhered to, since simply relying on a person's sense of smell has two fundamental problems:

1. An oxygen deficiency can't be smelled, nor can some dangerous gases or vapors.

2. Olfactory fatigue occurs such that after being in an environment for a while where a smellable gas is present, the ability to smell the gas diminishes or can even disappear.

As previously indicated, it is important that the air monitoring equipment be routinely calibrated and tested so that there can be confidence that it is performing properly.

IV. Routine Monitoring of Conditions In Hydraulic Piezometer Terminal Wells

A. General Overview

The conditions in every hydraulic piezometer terminal well, whether active or abandoned, should be periodically checked for possible evidence of development of a seepage-related failure mode. If the checks are routinely performed, such evidence should be detected at an early point in the development of the failure mode, which increases the number of possible response actions and decreases the likelihood that a large emergency discharge of reservoir water will be required.

B. Detailed Discussion

In most instances, the visual checks of a hydraulic piezometer terminal well can be performed at the same time the hydraulic piezometers are being read. However, circumstances may exist such that the frequency of the visual inspections may need to exceed the reading frequency for the hydraulic piezometers:

1. If hydraulic piezometers readings are required relatively infrequently.

2. If there are significant dam safety concerns relative to seepage into a terminal well.

3. If a terminal well has been abandoned and, therefore, no piezometer readings are routinely required.

In any event, specific guidance concerning the appropriate frequency for visually checking each hydraulic piezometer terminal well should be available from the current Schedule for Periodic Monitoring (L-23) and/or Ongoing Visual Inspection Checklist. If information concerning an appropriate visual monitoring frequency is not available, the Structural Behavior and Instrumentation Group in the TSC (D-8460) should be contacted to address this issue.

The first issue whenever a hydraulic piezometer terminal well is to be entered is

personal safety, so the considerations discussed in Section III. need to be addressed first. With safety considerations appropriately addressed, then the routine monitoring work relative to each hydraulic piezometer terminal well (active or abandoned) can proceed and should include the following:

1. Check for seepage at the tube bundle entrance location in the terminal well (the hole in the terminal well wall (typically the upstream wall) through which all the tubing passes):

- If measurable seepage is noted and it is not currently being monitored for flow rate and for possible sediment transport using a "catch basin" (or comparable method) that provides for continuous trapping of sediments, report this development to the area office and to D-8460 since such monitoring will need to be instituted. As best as possible, check for possible sediment transport by the seepage flow. If sediment transport is evident or suspected, report this development immediately as this will require a prompt technical evaluation.

- If seepage has been noted previously and methods are in place for monitoring the flow rate and possible sediment transport, note if any sediments have been collected. If so, report this development immediately as this will require a prompt technical evaluation. Also, record the seepage flow rate at the tube bundle entrance location and report this seepage data to D-8460 along with the other seepage and drain flow data collected at the damsite.

- If seepage has never been observed previously at the tube bundle location, and if no seepage is again observed, then note this on the Ongoing Visual Inspection Checklist. There should be a specific “YES” or “NO” question on the checklist. If there is not, request that the form be modified to address this matter.

2. Check for breaks or leaks at piezometer lines, at other hydraulic piping within the hydraulic piezometer terminal well, and at gauges in the terminal well. Any such breaks or leaks need to be promptly reported to D-8460 and repaired (sealed) to halt the flow of water out of the piezometer lines, gauges, and hydraulic piping. Breaks and leaks can lower the pressures being measured at the separate gauges, and can cause corrosion of separate gauges located below the leak or break.

If an abandoned terminal well has been backfilled with material such that entry into the well is not possible, all that can be done is to check for unusual seepage conditions in the vicinity of the well, such as new seepage areas, changed conditions at existing seepage areas, elevated flows at the toe drain in the area, changed water pressures at piezometers in the vicinity of the terminal well, and sinkholes or unusual depressions in the area.

C. Technical Comments

Appendix C consists of a technical paper titled: "Creation of Seepage Paths of Concern by Deteriorated Hydraulic Piezometer Installations" that includes discussion of:

1. Potential failure modes that could develop as a result of hydraulic piezometer installations in embankment dams.

2. Conditions and circumstances that increase or decrease the risks associated with potential failure modes associated with hydraulic piezometer installations.

3. Ways to appropriately manage the risk of development of the potential failure modes associated with hydraulic piezometer installations.

V. Routine Reading of Hydraulic Piezometers

A. General Overview

Obtaining routine readings at Reclamation hydraulic piezometer installations is straightforward and simple, as all that needs to be done is to read and record the indicated pressures on the two separate gauges associated with each piezometer. Since there are two separate gauges for each hydraulic piezometer at a standard installation, one on each of the two lines of tubing running to the terminal well, redundant data are collected that allow an immediate check on the data for apparent validity (either before, or preferably after adding the "separate gauge adjustment factor" discussed in Sections VI. and VII.). When gauge readings do not agree well, the first obvious check to be made is to ensure that a mistake in reading or recording the reading was not made.

B. Detailed Discussion

Whenever hydraulic piezometer readings are to be obtained, a hydraulic piezometer terminal well needs to be entered. The first issue is personal safety, so the considerations discussed in Section III. need to be addressed. With safety considerations appropriately addressed, then before obtaining any piezometer readings, the inspection work described in Section IV. should then be performed. When this work has been completed, one can then proceed with reading the inlet and outlet gauges for each piezometer and recording the readings on the appropriate data sheet. It is generally a good idea to lightly tap each separate gauge prior to recording its reading, just in case the indicator “arrow” of the gauge has gotten “hung up” due to contact with the face of the gauge or otherwise. Readings should be obtained to the nearest 1 foot on the 200-foot gauges, and to the nearest 2 feet on the 500-foot gauges. If a blank data collection form customized for the hydraulic piezometer installations to be read is not available, D-8460 can be contacted to obtain the needed form. An example data collection form is shown in Appendix E.

Traditionally, the standard guidance for deciding whether separate gauges were providing sufficiently accurate readings was to compare the readings for the two separate gauges for a piezometer. If they agreed within 5 feet for 200-foot-range separate gauges or 10 feet for 500-foot-range separate gauges, then the data were viewed to be acceptable. If they did not agree satisfactorily, then master gauge readings would be used (as discussed in Section VI.) as necessary to determine which of the gauges was producing out-of-line readings and needed to be replaced. With the development of the Annual Maintenance Report Form (AMRF), which is discussed in Section VI., the 5-foot or 10-foot tolerance test should now be performed on the "adjusted separate gauge readings" rather than on the "raw" separate gauge readings. See Section VII. for discussion concerning adjusted separate gauge readings.

If the adjusted separate gauge readings do not agree with each other, within the 5-foot or 10-foot tolerance limits, some maintenance work will be needed (assuming no errors were made in reading the gauges or recording the readings). If possible, it would be preferable to perform the needed maintenance work promptly, as described below, but an alternative would be to wait until the next time the annual maintenance work for the piezometers (described in Section VI.) is performed. It would be appropriate to contact D-8460 to discuss the situation in any event.

- The most easily remedied reason that separate gauge readings do not agree is that some air is present in the piezometer lines. Air can get into the lines by passing through the walls of the piezometer tubing, by being dissolved in water that enters the system at the piezometer tip or as “make up” water during flushing work, and by diffusion at the piezometer tip, most particularly for an instrument that varies between being in a saturated and an unsaturated environment. Air pockets impact the ability to obtain accurate piezometer water pressures because it is assumed that water (which has significant unit weight) will be present in the tubing rather than air (which has essentially no weight). As an example, for a piezometer located above its separate gauges in the terminal well, air in a vertical portion of the tubing will result in a lower separate gauge reading (and calculated piezometer water pressure) than would be the case if the tubing was entirely filled with water (as assumed). On the other hand, for a piezometer located below the terminal well, air in a vertical portion of the tubing will result in a higher separate gauge reading (and calculated piezometer water pressure) than would be the case if the tubing was entirely filled with water (as assumed). Therefore, flushing of the instrument's lines should be performed (after first flushing the manifold piping in the terminal well) to investigate this possibility (see Subsection IV.B.2.).

- The most obvious reason that the separate gauge readings might not

agree is that one or both of the gauges is not providing accurate data. If flushing the piezometer tubing does not bring the two separate gauge readings into close agreement, it will be necessary to replace one (or both) of the gauges. See Subsection IV.B.3. for the procedures for obtaining master gauge readings that can be used to determine which of the instrument gauges is defective and needs to be replaced. Gauges sometimes become stuck in one position, particularly for instruments where the water pressure at the piezometer location does not change significantly with changing reservoir levels. Lightly tapping each separate gauge prior to recording its reading, just in case the indicator "arrow" of the gauge has gotten "hung up" due to contact with the face of the gauge or otherwise, is always a good idea, as noted previously.

C. Technical Comments

It might seem that piezometer settlement caused by compression of embankment or foundation materials would lead to data inaccuracies because the adjustment factor accounting for the elevation difference between the piezometer and the separate gauges would no longer be accurate. However, even though the adjustment factor would not be accurate, the calculated water pressure for the piezometer would still be accurate. An example illustrating this is provided below:

> For a piezometer originally located at an elevation 10 feet above its associated separate gauges, but now only 9 feet above them, the water pressure at the instrument would be increased by 1 foot because of the settlement, since the weight of one more vertical foot of water is now acting on the piezometer (all other things being equal). However, the pressure felt by the separate gauges remains unchanged because the water pressure at the separate gauges due to the weight of water in the tubing is 1 foot less due to the settlement of the piezometer, which offsets the 1 foot pressure increase present at the piezometer.

The only negative impact of the piezometer settlement would be a slight inaccuracy in the location that it is perceived that the data is from.

By contrast, if the terminal well (and the separate gauges enclosed therein) settle, the calculated water pressures (measured in feet of water) would be (incorrectly) increased by the amount of the terminal well settlement (measured in feet) unless a correction was made for this settlement. In most instances, terminal well settlement is minor and does not need to be considered in making the water pressure calculations.

VI. Annual Maintenance of Hydraulic Piezometer Installations, Including Flusing the Lines and Obtaining Master Gauge Readings

Important Note: The discussion in this section assumes the valves in the terminal well are numbered consistent with what is shown schematically on Figures 6 and 7 (i.e. the well was constructed based on Drawing No. 40-D-4554 or Drawing No. 40-D-4664). For terminal wells that were constructed based on Drawing No. 40-D-6088 (shown schematically on Figure 8), refer to Appendix D. It is believed that only terminal wells at Heron, Scoggins, and Sugar Pine Dams were constructed based on Drawing No. 40-D-6088.

A. General Overview

The guidance provided in this section supercedes similar guidance provided on this subject in the 1987 Embankment Dams Instrumentation Manual.

The intent of the annual maintenance work, which includes flushing the piezometer tubing and checking the validity of each of the separate gauges, is as follows:

1. Eliminate air from within the piezometer tubing, which, if present, would lead to inaccurate data, as discussed in Section V.

2. Flush out bacterial material from within the piezometer tubing, which, if left unchecked, could grow and potentially plug off the tubing such that the instrument would eventually need to be abandoned as it could not be flushed, and therefore data from it would be suspect.

3. For each individual separate gauge, obtain a reading of it at the same time a master gauge reading is taken, with the same pressurized water acting on both gauges. After correcting for the elevation difference between the two gauges, the readings can be directly compared to determine if the separate gauge is functioning satisfactorily or if it needs to be replaced.

4. Based on the work and results of item 3. above, a correction value can be developed for each separate gauge so that readings from it can adjusted to the "most probable value", using all the information available from the master gauge work performed in the terminal well.

5. Gather important "performance" information about each piezometer installation, learned during the flushing work, and document it for future reference. Typically the information relates to water lost during flushing, and debris and/or air observed at the air trap during flushing. Sometimes, however, more unusual performance takes place during flushing and it is very valuable to

document what is observed so that appropriate actions can be taken regarding the piezometer in the future.

The "Annual Maintenance Report Form" (AMRF) has been developed to capture all the key data and information obtained in the course of the annual maintenance work. Copies of this form, customized for the dam where it will be used, are available from D-8460. An example of a blank AMRF is presented in Appendix F, and an example completed AMRF is presented in Appendix G.

B. Detailed Discussion

Whenever annual maintenance work concerning hydraulic piezometer installations in a terminal well is due to be performed, it will be necessary to enter the terminal well a couple times (at least). The first issue is personal safety, so the considerations discussed in Section III. need to be addressed. With safety considerations appropriately addressed, then before beginning the maintenance work, the opportunity should be taken to perform the inspection work described in Section VI. When this work has been completed, one can then proceed with the flushing and master gauge reading activity. The various steps associated with this work are discussed below.

1. Preparation Work

a. Obtain a blank "Annual Maintenance Report Form" (AMRF) that has been customized for use at the hydraulic piezometer terminal well in question. If a customized blank AMRF form is not available, D-8460 can be contacted to obtain one. An example blank AMRF is presented in Appendix F, and an example completed AMRF is presented in Appendix G.

b. Inspect the cartridge in the water-filter unit and replace it as necessary. It is vital that an effective water-filter unit be present in the hydraulic piezometer system to remove "debris" in the water dislodged by flushing work. A clogged cartridge will reduce the effectiveness of the pumps. In some instances, where the proper replacement cartridge is not on hand nor commercially available (discontinued product), then it may be necessary to replace the entire water-filter unit so that a serviceable filtering cartridge can be provided. D-8460 can be consulted if problems or difficulties arise in this area.

c. Inspect the air trap unit. If it is made of plexiglass, you should be able to see directly through the air trap and observe the water inside the trap. If you are unable to do this, the trap should be disassembled and thoroughly cleaned. If the air trap is a steel air trap, strong consideration should be given to replacing it with a plastic air trap (available from D-8460), so that monitoring of flushing work (i.e. monitoring the amount of debris and air flushed from the lines) can be effectively performed. If a steel air trap is being used, a sight glass usually is provided with the unit. If this sight glass is dirty such that viewing the water level is difficult,

then the steel air trap should be cleaned and the sight glass plastic tubing should be replaced. (Note: cleaning air traps will probably provide the additional benefit of reducing the frequency at which the water filter cartridges will need to be changed.) Clear vinyl scales should be located on the plastic air trap (or sight glass on a steel air trap) so that water level changes during flushing work can be accurately determined. These vinyl scales are available from D-8460.

d. To make sure that an adequate supply of “make-up water" is available during the flushing work, refill the water container (reservoir tank) in the terminal well with piezometer fluid consisting of distilled (or the best available) water to which 4 teaspoons of a 25-percent solution of QAC (Quaternary Ammonium Compound) has been added for each 10 gallons of replacement water. QAC is a bacterial inhibitor and wetting agent used to stop the growth of algae and help the flushing process effectively remove air bubbles. The Material Safety Data Sheet (MSDS) for the active ingredient in the QAC should be made readily available to operating personnel. D-8460 should be contacted if QAC, and the MSDS, is needed.

e. Make sure the electric pump is operable and functioning satisfactorily. While theoretically the hydraulic piezometer annual maintenance work could be accomplished using only a hand pump, this is not recommended. Realistically, an electric pump is needed. Electric pumps are not that expensive and pump replacement should promptly occur when circumstances warrant.

f. If the pressure at any of the separate gauges in the terminal well is negative, a functioning hand pump will be needed, so make sure it is operable and works satisfactorily. If none of the separate gauges shows a negative reading, then a functioning hand pump is not required.

2. Flushing Work Day

a. Preparation work prior to beginning flushing

i. Read and record the inlet and outlet separate gauge readings in column 1 of the AMRF before starting the flushing work to document the initial conditions.

ii. Check the entire system in the terminal well to ensure that all valves are closed. Close any valves that are not closed.

iii. Open the filler valve and the bleeder valve to the air trap. Fill the air trap with fluid to within 3 inches of the top of the plastic air trap or to the top of the sight glass for a steel air trap. Then close the filler and bleeder valves.

iv. IMPORTANT NOTE: Add fluid to the air trap, to the levels noted in step iii. above, any time during the course of the flushing work that the fluid level in the air trap drops below one-half full.

v. IMPORTANT NOTE: If the SOP for a dam includes site-specific instructions that differ from those presented in this section, follow the SOP instructions.

b. Flushing the manifold lines

i. Open the inlet and outlet valves to the electric pump (or hand pump, if for some reason it is being used).

ii. Open, in sequence, Valve Nos. 6, 3, 4, and 1.

iii. Start pumping and continue flushing this circuit until air bubbles no longer appear at the air trap.

iv. Close, in order, Valve Nos. 1, 4, and 6. (The electric pump may be left running.)

v. Open Valve No. 7, wait three minutes, and then close Valve No. 7. (This is done to allow any air bubbles in the line between Valve No. 7 and the master gauge to move vertically upwards into areas of the manifold lines where they can be removed by flushing performed in the next step.)

vi. Open, in sequence, Valve Nos. 5, 2, and 1 (Valve No. 3 is already open, from Step ii. above). Continue pumping and flush this circuit until air bubbles no longer appear at the air trap. Then close, in order, Valve Nos. 1, 2, 3, and 5.

vii. Open, in sequence, Valve Nos. 6, 2, and 1. Continue pumping and flush this circuit until air bubbles no longer appear at the air trap. Then close, in order, Valve Nos. 1, 2, and 6.

viii. Open Valve No. 7, wait three minutes, and then close Valve No. 7.

ix. Open, in sequence, Valve Nos. 5, 4, and 1. Continue pumping and flush this circuit until air bubbles no longer appear at the air trap. Then close, in order, Valve Nos. 1, 4, and 5.

c. Flushing the piezometer lines

Before proceeding with this flushing work, the following information should be reviewed:

- Valve No. 1 is used to throttle, or control, the pressure applied during direct and reverse flushing of each piezometer. Valve No. 1 should be opened and closed slowly to prevent surges of pressure when circulating water in the system. Valve No. 1 must be a needle valve, so that the needed throttling can be performed. A ball valve, or a series of ball valves, will not work.

- During direct flushing of a piezometer (water is being pumped into the inlet line and returning through the outlet line), the inlet gauge reading should exceed the corresponding AMRF column 1 value for the inlet gauge by approximately 30 feet. This provides sufficient pressure to create suitable flow through the piezometer line, yet avoids the introduction of excessive pressures into the dam embankment or foundation at the piezometer due to the flushing work. During direct flushing, the outlet gauge reading will be much lower and generally near zero. (See the bullet item below if the outlet gauge reading is below zero.) Observing inlet and outlet gauge readings as described above indicates that flushing is occurring. If the readings are not at approximately in line with the indicated values, then effective flushing is not occurring and the situation needs to be rectified so that effective flushing work can be performed. In all likelihood, pump repair or replacement is needed.

- Throttle (partially close) Valve No. 4 during direct flushing as necessary so that a vacuum does not develop on the return line to the air trap. A reading below zero on the outlet gauge would indicate the need for performing this throttling. Close monitoring of the outlet gauge for the piezometer during direct flushing is important. The small back pressure created by this throttling may also help air bubbles move along in the return line.

- During reverse flushing of a piezometer (water is being pumped into the outlet line and returning through the inlet line), the outlet gauge reading should exceed the corresponding AMRF column 1 value for the outlet gauge by approximately 30 feet, and the inlet gauge reading will be much lower, generally near zero, for the same reasons as discussed above. (See the next bullet item below if the inlet gauge reading is below zero.) Again, observing inlet and outlet gauge readings as described herein indicates that reverse flushing is occurring. If the readings are not approximately in line with the indicated values, then effective reverse flushing is not occurring and the situation needs to be rectified. Again, in all likelihood, pump repair or replacement is needed.

- Throttle (partially close) Valve No. 2 during reverse flushing as necessary so that a vacuum does not develop on the return line to the air trap. A reading below zero on the inlet gauge would indicate the need for performing this throttling. Close monitoring of the inlet gauge for the piezometer during reverse flushing is important. The small back pressure created by this throttling may also help air bubbles move along in the return line.

- Some small air bubbles may not be removed during direct or reverse flushing, particularly if they are situated in nooks or crannies in the system where flushing of the system is most difficult. Sometimes closing and opening the outlet valve during direct flushing, and the inlet valve during reverse flushing, helps to remove an air bubble trapped within the return line during flushing.

- During all flushing work, visually monitor the air trap and record in column 4 of the AMFR any noteworthy observations, such as a significant quantity of air bubbles was noted, discolored water or debris was observed, an appreciable fall (or rise) in the fluid level occurred (note approximately how much the water level changed, should this occur), etc.

- The flushing time for each flushing operation (direct flush or reverse flush) should be as indicated on the AMRF. When flushing has been performed for at least the minimum time indicated, the flushing operation may be terminated when no bubbles or debris appear in the air trap for at least three minutes. The indicated flushing times are based on the distance of each piezometer from the terminal well. The "standard" flushing time is 5 to 15 minutes, and applies to piezometers within 500 feet of the terminal well. Greater flushing times are required for more distant instruments, as indicated on the AMRF. For instance, a piezometer 1,000 feet from the terminal well typically will require a flushing time of 20 to 30 minutes.

- If substantial amounts of fluid are being lost during a flushing operation, judgment can be used that flushing should be halted, and notes to that effect should be provided on the AMRF in column 4. However, it is important to note that for many piezometers (such as piezometers in a pervious zone of the dam embankment or foundation), loss of some fluid during flushing is normal.

- If there is no return flow, yet appropriate pressures on the piezometer line are being provided by the pump, then the piezometer line may be plugged. The attempt at flushing the line can be terminated after 5 minutes, and appropriate comments about what occurred should be recorded in column 4 of the AMRF.

- If water treated with QAC is introduced into piezometer lines that has not had QAC-treated water in it for awhile (say a year or more), the tubing may turn black as the QAC kills off a substantial population of bacteria that got out of control due to the lack of QAC in the previous months (and possibly years). This may appear alarming, but it is not a problem as the inert black matter will be cleared from the tubing the next time flushing work is performed. QAC-treated water also may give off an odor (such as burning oil or rubber) when it has not been used in the system for a while. Care should be taken to avoid QAC-treated water from coming in contact with the electric pump when it is hot, as this could produce a very pungent odor in the well.

- Sometimes water cannot be circulated in hydraulic piezometer lines because insufficient pumping pressures are being developed. (Sometimes in these situations the tubing is reported to be plugged because the inadequacy of the pump is not recognized.) Inspection of the separate gauge readings recorded in AMRF columns 2 and 3 can quickly reveal why no water circulation occurred, due to insufficient pumping pressures, if pressures approximately 30 feet above the

column 1 values were not achieved. If appropriate pressures can not be developed by the pump, then pump repair or replacement is indicated, unless the problem lies with the setting or operation of the bypass pressure relief valve. D-8460 should be consulted if the necessary pumping pressures can not be developed, yet the pump appears to be operating satisfactorily. D-8460 can also be consulted relative to pump repair or replacement needs.

With the above information in mind, the specific procedures to be used in flushing the piezometer lines are noted below:

i. Open, in sequence, Valve Nos. 6, 4, and 1. Then slowly open the inlet and outlet valves for one piezometer and flush the lines for this instrument. This is direct flushing. Record the approximate gauge readings of the inlet and outlet separate gauges in column 2 of the AMRF. Record observations during the direct flushing in column 4 of the AMRF. When direct flushing has been completed, close in sequence Valve Nos. 6 and 4, and record the actual flushing time on the "Inlet" line of AMRF column 5.

ii. Open, in sequence, Valve Nos. 5, and 2 and continue flushing. This is reverse flushing. Record the approximate gauge readings of the inlet and outlet separate gauges in column 3. Record observations during the reverse flushing in column 4 of the AMRF. When reverse flushing has been completed, close in sequence Valve Nos. 1, 2, and 5 and the inlet and outlet valves for the piezometer. Record the actual time reverse flushing was performed on the "Outlet" line of AMRF column 5.

iii. Repeat Steps i. and ii. for each piezometer in the terminal well, unless specific instructions exist to not flush particular instruments. (Such instructions should be noted on the AMRF.)

After this flushing work is completed, shut off the pump and close all valves in the terminal well, including the pump valves.

3. Master Gauge Reading Day

a. General

The Master Gauge Reading Day should be at least one week after the Flushing Work Day (to allow the piezometers to return toward equilibrium or near-equilibrium conditions after the flushing work), but not more than 1 month after Flushing Work Day (so that there is reasonable assurance that there is no air in any of the piezometer lines).

In general terms, the master gauge work consists conceptually of the following. Each separate gauge is addressed in turn. Fluid in the manifold line is pressurized to bring the reading at the master gauge to approximately the AMRF column 6

value for the separate gauge (within a couple feet). Then the valve to the separate gauge is opened to allow the same "pressurized water" to act simultaneously on the separate and master gauges. The separate and master gauge readings under these conditions are recorded in columns 7 and 8, respectively, on the AMRF, on the appropriate line. This information allows a check of the accuracy of each separate gauge, using the master gauge as the benchmark.

If the SOP for a dam includes site-specific instructions that differ from those presented in this section, follow the SOP instructions.

b. Check the AMRF column 10 values, if necessary

This step is only needed if separate gauge replacement work has occurred since the last time the AMRF form has been used. If this is the case, check the values already present in column 10 of the AMRF to ensure they are approximately correct. They represent the elevation of the separate gauge minus the elevation of the master gauge, rounded to the nearest ½ foot. A "+1.5" value means that the separate gauge is approximately 1.5 feet higher than the master gauge. The measuring point is to the center of the gauge. Any column 10 values that are not correct should be crossed out and the appropriate values should be indicated.

c. Initial separate gauge readings

Read the inlet and outlet separate gauges and record these readings in column 6 of the AMRF before starting the master gauge reading work. (These readings could be considered the "best" readings that will be obtained for the year, as the piezometer tubing has just recently been flushed.)

d. Flush the manifold lines and prepare to obtain master gauge readings

i. Check the entire system in the terminal well to ensure that all valves are closed. Close any valves that are not closed.

ii. Open the filler valve and the bleeder valve to the air trap. Fill the air trap with fluid to within 3 inches of the top of the plastic air trap or to the top of the sight glass for a steel air trap. Then close the filler and bleeder valves.

iii. IMPORTANT NOTE: Add fluid to the air trap, to the levels noted in step ii. above, any time during the course of the flushing work that the fluid level in the air trap drops below one-half full.

iv. Flush the manifold lines in the terminal as described above in section IV.B.2.b.

v. With the inlet and outlet valves to the electric pump (or hand pump, if for some reason it is being used) open, follow the appropriate instructions in the following

four subsections so that master gauge readings are obtained for all the separate gauges in the terminal well.

e. Obtaining master gauge reading data for an inlet separate gauge when the inlet separate gauge shows a positive reading

i. With the pump running, open in sequence Valve Nos. 1, 6, 2, and 7. Throttle Valve No. 1 and slowly close Valve Nos. 1 and 2 so as to set a pressure on the master gauge that is approximately the same as the Column 6 value on the AMRF for the separate gauge. Stop pumping when Valve Nos. 1 and 2 are fully closed.

ii. Open the inlet valve to the inlet separate gauge, let the separate gauge and master gauge stabilize on their readings (for the same pressurized water), and record the appropriate values in Columns 7 and 8 on the AMRF.

iii. Close the inlet valve to the inlet separate gauge.

iv. Open Valve No. 2 to relieve the water pressure in the manifold lines, and then close Valve No. 2.

v. Close Valve Nos. 6 and 7.

f. Obtaining master gauge reading data for an outlet separate gauge when the outlet separate gauge shows a positive reading

i. With the pump running, open in sequence Valve Nos. 1, 5, 4, and 7. Throttle Valve No. 1 and slowly close Valve Nos. 1 and 4 so as to set a pressure on the master gauge that is approximately the same as the Column 6 value on the AMRF for the separate gauge. Stop pumping when Valve Nos. 1 and 4 are fully closed.

ii. Open the outlet valve to the separate gauge, let the separate gauge and master gauge stabilize on their readings (for the same pressurized water), and record the appropriate values in Columns 7 and 8 on the AMRF.

iii. Close the outlet valve to the outlet separate gauge.

iv. Open Valve No. 4 to relieve the water pressure in the manifold lines, and then close Valve No. 4.

v. Close Valve Nos. 5 and 7.

g. Obtaining master gauge reading data for an inlet separate gauge when the inlet separate gauge shows a negative reading

i. Turn off the electric pump and close the inlet and outlet valves for the electric

pump.

ii. Open the outlet valve on the hand pump and open Valve No. 1. (The inlet valve on the hand pump should remain closed.)

iii. Check to see if the handle on the hand pump is in the down position. If it is not, open Valve Nos. 5 and 4, push the handle to the down position, and then close Valve Nos. 5 and 4.

iv. Open Valve Nos. 6 and 7.

v. Apply a suction stroke on the hand pump by pulling up on the pump handle.

vi. Quickly close Valve No. 1, and then throttle and re-close Valve No. 1 so as to set a pressure on the master gauge that is approximately the same as the Column 6 value on the AMRF for the separate gauge.

vii. Open the inlet valve to the separate gauge, let the separate gauge and master gauge stabilize on their readings (for the same negative pressure), and record the appropriate values in Columns 7 and 8 on the AMRF.

viii. Close the inlet valve to the inlet separate gauge.

ix. Open Valve No. 2 to eliminate the negative water pressure in the manifold lines, and then close Valve No. 2.

x. Close Valve Nos. 6 and 7.

h. Obtaining master gauge reading data for an outlet separate gauge when the outlet separate gauge shows a negative reading

i. Turn off the electric pump and close the inlet and outlet valves for the electric pump.

ii. Open the outlet valve on the hand pump and open Valve No. 1. (The inlet valve on the hand pump should remain closed.)

iii. Check to see if the handle on the hand pump is in the down position. If it is not, open Valve Nos. 5 and 4, push the handle to the down position, and then close Valve Nos. 5 and 4.

iv. Open Valve Nos. 5 and 7.

v. Apply a suction stroke on the hand pump by pulling up on the pump handle.

vi. Quickly close Valve No. 1, and then throttle and re-close Valve No. 1 so as to

set a pressure on the master gauge that is approximately the same as the Column 6 value on the AMRF for the separate gauge.

vii. Open the outlet valve to the separate gauge, let the separate gauge and master gauge stabilize on their readings (for the same negative pressure), and record the appropriate values in Columns 7 and 8 on the AMRF.

viii. Close the outlet valve to the outlet separate gauge.

ix. Open Valve No. 4 to eliminate the negative water pressure in the manifold lines, and then close Valve No. 4.

x. Close Valve Nos. 5 and 7.

i. At the conclusion of master gauge reading work

After all the master gauge reading work has been completed, be sure the electric pump is shut off and close all valves in the terminal well, including the pump valves.

4. Calculations

Columns 9 and 11 of the AMRF do not need to be completed before mailing the form to D-8460, but all other areas of the AMRF form do need to be filled in, including the heading information on each sheet, columns 1 through 8 of the main table of the form, and the comments area on the last sheet (if needed due to insufficient space available in AMRF column 4, or if space is needed for other notes or comments). For information purposes only, columns 9, 10, and 11, and the Master Gauge Correction Factor are discussed below:

a. Column 9 is simply a calculated entry, column 7 minus column 8, showing the difference between separate gauge and master gauge readings of the same "pressurized" water during the master gauge reading work. However, since the separate and master gauges are typically not installed at the same elevation, even separate and master gauges that are in perfect agreement will typically produce a non-zero value in column 9.

b. Column 10 is a "constant value" reflecting the elevation difference between the separate gauge and the master gauge (separate gauge elevation minus master gauge elevation), as noted above. If the separate gauge and master gauge readings recorded in columns 7 and 8, respectively, are in perfect agreement, then the value in column 9 will agree exactly with the value in column 10.

c. The Master Gauge Correction Factor is based on the idea that while the master gauge is a useful reference gauge, and generally would be expected to be highly accurate, it may not be exactly accurate (in an absolute sense) in all cases. In a simplified example, if there were 50 separate gauges and all the column 9 values were exactly 5 feet greater than the column 10 values, it would be more

reasonable to conclude that the master gauge was reading 5 feet too low, rather than that all 50 separate gauges were reading too high by exactly the same amount (5 feet). This sort of logic is the basis for the Master Gauge Correction Factor. If the average of a number of different independent separate gauge readings is significantly different than the corresponding adjusted master gauge readings, then the error in the absolute pressure values more likely lies with the single master gauge reading than with all the separate gauge readings. The Master Gauge Correction Factor is used in calculating the column 11 values and is a positive number if the master gauge is reading too low. The Master Gauge Correction Factor is calculated as shown at the bottom of page 1 of the AMRF, using only the data from those separate gauges where apparently valid data is present in both columns 7 and 8. (Crossing out apparently invalid data on the AMRF makes it easy to see which rows of data should be excluded from this calculation.) The Master Gauge Correction Factor should be rounded to an accuracy no greater than 0.25 foot. If the Master Gauge Correction Factor is large, replacement of the master gauge may be appropriate.

d. Column 11 is the calculated adjustment factor to be applied to the raw separate gauge readings to bring each individual separate gauge reading to the most appropriate reading, based on the information available from the master gauge work. For each separate gauge, the column 11 value is calculated by taking the corresponding column 10 value, subtracting the corresponding column 9 value, and adding the Master Gauge Correction Factor.

C. Technical Comments

With the information now available from the AMRF, processing of hydraulic piezometer data and decisions about separate gauge replacement can proceed with more sophistication than the procedures previously used. Piezometer water pressures used in dam safety evaluation work should be based on adjusted separate gauge readings (based on the column 11 information), since this would represent the best estimate of the actual water pressure, using all the information available. In the same vein, the 5 foot and 10 foot agreement tests for determining apparent separate gauge data validity should be applied to <u>corrected</u> separate gauge readings (column 6 plus column 11) rather than to the raw data (column 6).

A comparison of AMRF column 6 values with column 1 values provides a quick look at the impact of the flushing work (assuming no great change in the reservoir level between the flushing day and the master gauge day).

VII. Processing and Evaluating Hydraulic Piezometer Data

A. General Overview

When entering a set of hydraulic piezometer readings (separate gauge readings) into the Reclamation Instrumentation Computer Database, called DAMS (Data

Acquisition and Management System), DAMS will prompt for the inlet and outlet gauge reading for each piezometer, and automatically compute a piezometric water level, if the data appear to be valid. If the data do not appear to be valid, the data entry program in DAMS will accept the raw readings and store them, but will not compute and store a water level using the suspect data. Instead, the program will indicate that invalid data have been obtained. Prompt investigation of the problem should be initiated.

B. Detailed Discussion

If a completed Annual Maintenance Report Form (AMRF) is not yet available for the hydraulic piezometer installation in question, then DAMS will judge apparent data validity based on the following criteria:

> Data for a piezometer will be considered valid if the separate gauge readings agree within 5 feet for 200-foot-range gauges and 10 feet for 500-foot-range gauges.

If one or more completed AMRF forms are available, then DAMS will judge apparent data validity based on the following criteria:

> Data for a piezometer will be considered valid if the <u>adjusted</u> separate gauge readings agree within 5 feet for 200-foot-range gauges and 10 feet for 500-foot-range gauges.

The adjustment to the data will be based on information from AMRF column 11. If more than one AMRF is available, the history of column 11 values and engineering judgment will be used by D-8460 personnel to establish an appropriate adjustment value to be used in processing future data, as well as appropriate adjustments to be applied to past data. These adjustments can be revised at any time as new information becomes available. Detailed discussion concerning the AMRF is provided in Section VI.

The piezometric water surface elevation (in feet) for each piezometer is determined by the DAMS system using the following process:

1. The "raw" separate gauge readings are adjusted using a "separate gauge correction amount" (assuming the necessary data are available to make the adjustment). The rationale for this adjustment is discussed in detail in Section VI. relative to the Annual Maintenance Report Form (AMRF). Basically this adjustment involves using information gained from the annual master gauge readings (discussed in Section VI.) to account for separate gauges that historically read a bit high or low. This correction factor is added to the raw gauge readings to produce "adjusted separate gauge readings." Until publication of these guidelines, this adjustment historically has not been made, but it is now recognized as an obvious way to improve the quality of the hydraulic piezometer pressure data.

2. The two adjusted separate gauge readings associated with each piezometer are averaged, the tip elevation is added to this average value, and a correction factor (the tip constant) is added to or subtracted from this value to account for the elevation difference between the piezometer tip and the separate gauges for the instrument. To clarify the need for this last adjustment factor, the following example is provided:

> The separate gauge readings (in feet of water pressure) for a piezometer located at an elevation 10 feet above its associated separate gauges should be 10 feet higher than the pressure at the piezometer (due to the weight of the water in the piezometer tubing), so 10 feet must be subtracted from the pressure gauge reading to get the actual pressure at the piezometer.

Where a hydraulic piezometer is being read as single-tube installation, the data entry program can be set up to accept data for this situation, and will then only "prompt" for the applicable gauge (inlet or outlet). A single-tube installation typically occurs due to plugging of the piezometer tubing such that one separate gauge is isolated from the piezometer by the plug so that the gauge no longer has any value since it is not hydraulically connected to the piezometer. Readings of the remaining separate gauge can be made and may provide useful data, at least for a period of time. However, data from single-tube installations must be viewed with great caution because:

1. The installations cannot be flushed, so air or bacterial growth resulting in plugging could occur between the piezometer and the operating sensor which could: (a) not be known to exist, (b) not be removed, and (c) adversely impact the data.

2. Without a second tubing line to the terminal well and a separate gauge on the second line, there is no way to independently check the data of the operational gauge for the problems noted above. Master gauge readings can assure that the gauge is accurate (and appropriate separate gauge correction amounts can be determined), but nothing can assure proper conditions exist in the tubing between the gauge and the piezometer.

Often, a single-tube piezometer apparently provides useful data for a period of time after becoming a single-tube installation, but as time passes, the suspicions concerning the data, due to the unflushed tubing, eventually lead to its abandonment because the data can no longer be viewed with confidence. The time period during which useful data are still obtained is very instrument-dependent, since it relates to the ability of air to get into the line and impact the data, or the ability of microorganisms to plug off the line.

C. Technical Comments

Decisions concerning appropriate AMRF-based adjustments to previously processed and stored separate gauge data can always be revised, in the same vein that current adjustment values can be revised. The DAMS system will allow storage of the raw data (separate gauge readings), the AMRF-based adjustment values (to be stored as "changeable constant values"), the piezometer tip elevations, the elevation differences between the piezometers and the separate gauges (generally constant assuming the separate gauges do not get moved in the terminal well and significant terminal well settlement does not occur), and the calculated piezometric water surface elevations (computed using the other four sets of data). The AMRF-based adjustment values may be set to vary over time, if this is desired to effectively deal with historical data, and past and current adjustment values may be revised at any time as appropriate. When revisions are made to any of the "constants" used in the calculations that would affect past computed water surface elevations, the elevation data are simply re-computed using the revised "constants" and replace the previous piezometric water surface elevation data. While determining appropriate AMRF-based adjustments may be challenging and difficult at times, the true accuracy of the data, as well as the understanding of the data, should be substantially improved when compared to the alternative of simply ignoring information that allows logical adjustment and improvement of the data.

VIII. Formal Inspection of Hydraulic Piezometer Installations

Whenever an Annual Inspection, Periodic Facility Review, or Comprehensive Facility Review inspection of the dam is performed, the inspection should include:

1. Performing the "dam safety" inspection work defined in Section VI. (Routine Monitoring of Conditions in Hydraulic Piezometer Terminal Wells).

2. Inspecting the hydraulic piezometer installations for O&M (operations and maintenance) issues. Of particular concern would be matters relating to the safety of operating personnel, including checking the condition and performance of ventilating equipment, checking that access to and egress from the hydraulic piezometer installations can be accomplished safely (e.g. “ladder-ups” provided as appropriate), checking the condition of the frost floor, checking that GFIs (Ground Fault Interruptors) are provided for electrical circuits, and ensuring that "housekeeping" is such that the terminal well is a safe work environment (e.g. mice are not frequenting the well such that hantavirus is a concern). Also, protection provided relative to potential vandalism is of great concern. A lock should be provided at the access door, and the lock should be designed to withstand prying with a crowbar and damage from a large rock dropped onto it. Similarly, the cover over the terminal well should be capable of withstanding large rocks being dropped on it such that vandals would not be able to gain access into the well. Additionally, if a sump pump is present in the well to prevent

flooding, it should be inspected and checked, as the potential exists for substantial and costly damage in the well should it fail. Obviously, the general state of maintenance and repairs needs to be addressed as well.

IX. Discussion of Hydraulic Piezometer System Components, Including Repair and Replacement Issues

A. General Overview

Figures 6, 7, and 8 show schematic views of the "typical" equipment associated with standard Reclamation hydraulic piezometer installations. Only 1 hydraulic piezometer is shown in this illustration, but generally about 20 to 30 piezometers might be tied into one terminal well, with their connection points to the manifold piping in the well all being in the same relative location as shown on Figures 6, 7, and 8 (on either side of the Manifold Flushing Valve, Valve No. 3). Each piezometer would have its own outlet line, inlet line, outlet gauge, inlet gauge, outlet valve, and inlet valve. Except for the actual hydraulic piezometer itself, and the majority of the outlet and inlet lines, all the equipment shown in Figures 6, 7, and 8 is present within the terminal well, and therefore can be repaired and/or replaced to keep the installation operational. Personnel from D-8460 are available to provide assistance to relative to such repair or replacement work, and should be contacted relative to obtaining appropriate equipment and materials needed for repair/replacement work. In particular, air traps, bypass relief valves for pumps, and pressure check valves for pump circuits and master gauges should only be ordered by D-8460, because of the nature of the equipment. Also, bulk purchases of master gauges by D-8460 allows these gauges to be obtained much more economically. The most common problem that cannot be rectified (and therefore leads to loss of piezometers) is when piezometer tubing breaks or becomes plugged in a location outside of the terminal well. Tubing breaks occur because of the tubing material and system layout that were decided upon during the installation design and are therefore beyond the control of current O&M efforts. However, plugged tubing typically is associated with poor routine maintenance work and can be avoided if the provisions of Section VI. are faithfully carried out.

B. Detailed Discussion

The Embankment Dam Instrumentation Manual provides extensive discussion concerning the equipment used in hydraulic piezometer installations. In this section, no effort will be made to repeat all the information the manual provides. Instead, some key practical information will be presented relative to repair and replacement of hydraulic piezometer equipment. Assistance from D-8460 may be sought in dealing with repair and replacement issues, and since this work arises only infrequently (at least it is hoped), it is generally wise to consult with D-8460 personnel whenever such work needs to be performed.

1. Piezometer tip assembly.- This is included only for completeness as there is obviously no opportunity to readily replace the piezometers that are embedded in embankment material (see Figure 1 for illustration) or located in drill holes in the foundation (see Figure 2 for illustration). The porous filter used to allow water and water pressure to communicate with the interior chamber of the piezometer, but to prevent embankment and foundation material from entering, has a small effective opening size (rough 1-2 microns) to also limit the amount of air that can get into the piezometer. This is important for instruments where the water level fluctuates above and below the level of the piezometer, depending on the reservoir level.

2. Tubing (inlet and outlet lines).- Over the years, tubing has been made of copper, polyvinyl chloride (Saran plastic), polyethylene plastic, and polypropylene plastic. The tubing types used at Reclamation dams having hydraulic piezometer installations are indicated in Appendix A. Tubing employing a nylon inner tube and a polypropylene jacket would be the current recommendation in the event of a desire to construct new hydraulic piezometer installations. For tubing replacement inside an existing terminal well, current Reclamation practice is to use polyethylene plastic tubing.

3. Compression fittings.- Compression fittings are available from D-8460 that are much less likely to crack the piezometer tubing than the fittings available at a typical retail hardware store, so their use is recommended.

4. Separate gauges (inlet and outlet gauges).- The "T" connections on the separate gauges that are in current use have unintentional air traps in them, so they should be installed at a slight vertical angle (say 5E) to allow air to be moved out by normal flushing work.

If maintenance/repair work is done that results in relocation of separate gauges in a terminal well to different elevations, the AMRF column 10 values and the constant values added to the separate gauge readings to convert them to piezometer water surface elevations both will need to be modified, so obviously D-8460 will need to be informed of such separate gauge relocations.

5. Inlet and outlet valves.- These are brass ball valves.

6. Operating valves in the well (Nos. 1 thru 7).- Valve No. 1 is used to throttle or control the pressure applied by the pumps and must be a needle valve. A ball valve is an on/off valve and will not perform the necessary throttling function. Valve No. 1 should be opened and closed slowly to prevent surges of pressure when circulating water in the system. Valves No. 2 through No. 7 are brass plug-type shutoff (on/off) valves.

7. Master gauge.- This is a larger, more accurate gauge than the separate gauges.

It is current practice to install a pressure check valve on the manifold piping running to the master gauge to minimize the chances of having pressure shocks on the master gauge. This protection typically is not in place at most terminal wells, but when an opportunity arises to install it, it would be a good idea.

8. Air trap.- Clear plastic air traps are strongly preferred over steel pipe traps that only have a clear water level monitoring tube (sight glass) installed in parallel with the air trap. Clear air traps allow observation of bubbles and/or debris entering the air trap, which makes it possible to effectively monitor the results of flushing work. Steel air traps do not allow monitoring of this important information, and therefore should be replaced with clear plastic air traps. Clear plastic air traps are available from D-8460. Air traps should have a scale mounted on the unit for measuring water loss or gain during flushing.

9. Filter unit.- The water filter unit needs to be installed downstream of the air trap. As noted in Section VI., in some instances where proper replacement cartridges are not on hand nor commercially available (discontinued product), it may be necessary to replace the entire water-filter unit so that an serviceable filtering cartridge can be provided. D-8460 can be consulted if problems or difficulties arise in this area.

10. Electric and hand pumps.- If the pumps cannot generate sufficient pressure, flushing efforts will be compromised. Specifically, if pressures approximately 30 feet higher than the Annual Maintenance Report Form (AMRF) column 1 values can not be generated at the separate gauges during direct and reverse flushing (as discussed in Section VI.), then the pumps are not adequate for the required flushing work. While theoretically the hydraulic piezometer annual maintenance work can be accomplished using only a hand pump, realistically an electric pump is needed. Electric pumps are not that expensive so functioning electric pumps should be provided in all terminal wells. If the pressure at any of the separate gauges in the terminal read is negative, a hand pump will be needed for carrying out master gauge readings. If none of the separate gauges shows a negative reading, then a functioning hand pump is not required.

The hand pump requires the use of gravity-lift check valves on the inlet and outlet sides of the pump. These valves are not typically supplied when a hand pump is ordered, and therefore must be ordered separately. These valves must be installed horizontally, so that gravity can allow the valve to function as intended. When properly installed, these valves make it possible for the hand pump to develop negative (suction) pressures in the terminal well manifold lines.

11. Bypass relief valve.- This relief valve is intended to prevent excessive pressures, that could be developed by the pumps, from being applied to the separate gauges or master gauges. 200-foot-range gauges require a relief valve that will release to the bypass line at no higher than approximately 95 lb/in^2.

(Note that 200-foot-range gauges can actually tolerate pressures of up to 231 feet of water.) Similarly, 500-foot-range gauges require a valve setting of 215 lb/in^2 or less. The pressure relief valve may be set at a lower pressure than the upper limit values noted above, but the setting must be high enough to allow sufficient flushing pressure at all piezometers, which is 30 feet of head higher than the highest pressure anticipated. The release pressure for the valve is preset at the factory, but typically needs to be adjusted by D-8460 personnel as a part of the installation work. When installed, sufficient pressure should be applied to the valve to check that it opens at the desired pressure. Note that when master gauge readings are obtained, and Valve No. 1 is be throttled to a closed position, the pressure on the "pump side" of Valve No. 1 builds quickly and the bypass relief valve opens and closes to keep the pump from overheating.

12. Pressure check valve.- This valve is located between the pumps and the cartridge-type water filter unit. It prevents back pressure into the water filter unit and air trap when the bypass relief valve operates, which is particularly important when a plastic air trap is installed. The pressure check valves typically have a 1 psi opening pressure, but a few hydraulic piezometer installations have required 1/3 psi units.

13. Manifold piping.- Generally this is 1/4-inch standard brass pipe. For replacement pipe, 3/8-inch-diameter plastic tubing has been used.

14. Water.- The water used in hydraulic piezometer systems should be distilled (or the best available) water, to which 4 teaspoons of a 25-percent solution of QAC (Quaternary Ammonium Compound) has been added for each 10 gallons of water. QAC is a bacterial inhibitor and wetting agent used to stop the growth of algae and help the flushing process effectively remove air bubbles. QAC can and should be obtained from D-8460. Various QAC solutions can be used, including those derived from benzethonium chloride, produced by Spectrum Quality Products Inc., Hyamine, produced by Rohm and Hass Co., and BTC or Onyxide, produced by Onyx Oil and Chemical Co. The Material Safety Data Sheet (MSDS) for the active ingredient in the QAC should be made readily available to operating personnel.

15. Ventilation equipment.- The ability to ventilate a terminal well is required so that personnel can safely enter and work in the well, as indicated in Section III. Therefore, ventilation equipment is needed that is in good working order. The ventilation equipment needs to be carefully inspected whenever an Annual Inspection, Periodic Facility Review, or Comprehensive Facility Review inspection of the dam is performed, and appropriate recommendations concerning the equipment need to be made as warranted.

16. Frost floor.- The purpose of the frost floor is to prevent freezing temperatures in the area of the terminal well below the floor. Since water expands upon

freezing, freezing temperatures could result in damage to water-filled piezometer tubing. Gauges and other equipment could also be damaged by freezing temperatures. Besides their fundamental purpose, frost floors also provide a landing to break up the ladder descent and ascent in the well, and provide space that can be used for storage in the well.

X. Abandonment of Hydraulic Piezometer Systems

The determination to abandon all the active piezometers at a terminal well (and therefore abandon the terminal well) should only be made at the time a CFR is performed relative to the dam. The CFR process includes a formal evaluation of the dam's current dam safety performance monitoring needs, involving TSC, regional office and area office personnel, and as such represents the right forum for determining appropriate changes to the monitoring program. (such as abandoning piezometers).

No grouting of hydraulic tubing or backfilling of terminal wells should be performed relative to abandoned installations, unless a specific recommendation is made to perform this work. Reclamation's technical guidance at this time relative to grouting of tubing is that it would not be wise to engage in this work at this time, using currently available materials and methods. As advances in materials and/or methods occur in the future, there may come a time when grouting of tubing would be recommended. However, as of now, that time has not arrived. Relative to backfilling of terminal wells, Reclamation's technical guidance at this time is that it is best to be able to monitor possible seepage into abandoned terminal wells, rather than being precluded from doing so. Therefore, the backfilling of terminal wells is not seen to be beneficial. Refer to Appendix B for extended discussion of the rationale relative to the abandonment of hydraulic piezometer terminal wells.

Routine monitoring of abandoned terminal wells for seepage, leaks, and tubing breaks (that could relate to seepage-related failure modes for the dam) should be performed, as noted previously in Section IV.

XI. Figures

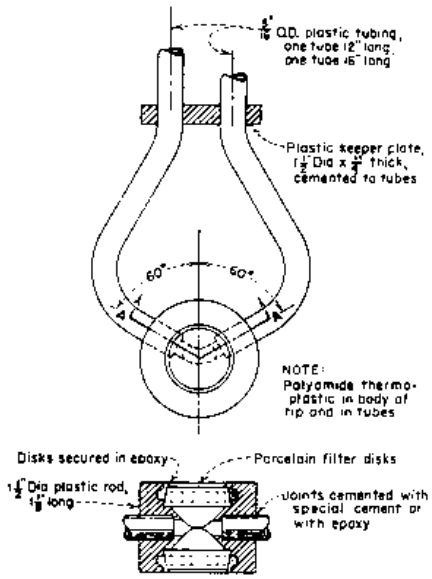

Figure 1.- Details of the type of hydraulic piezometer that would be installed in embankment material (from Figure 2-7 of the Embankment Dam Instrumentation Manual)

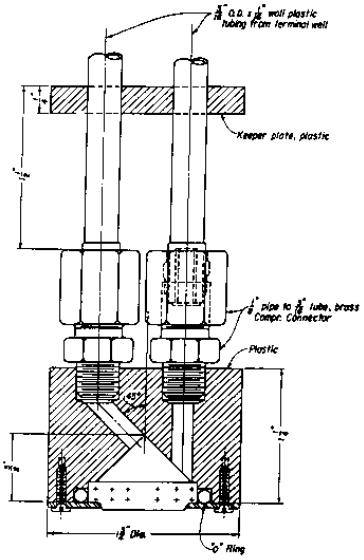

Figure 2.- Details of the type of hydraulic piezometer that would be installed in a drill hole in the foundation of a dam (from Figure 2-8 of the Embankment Dam Instrumentation Manual)

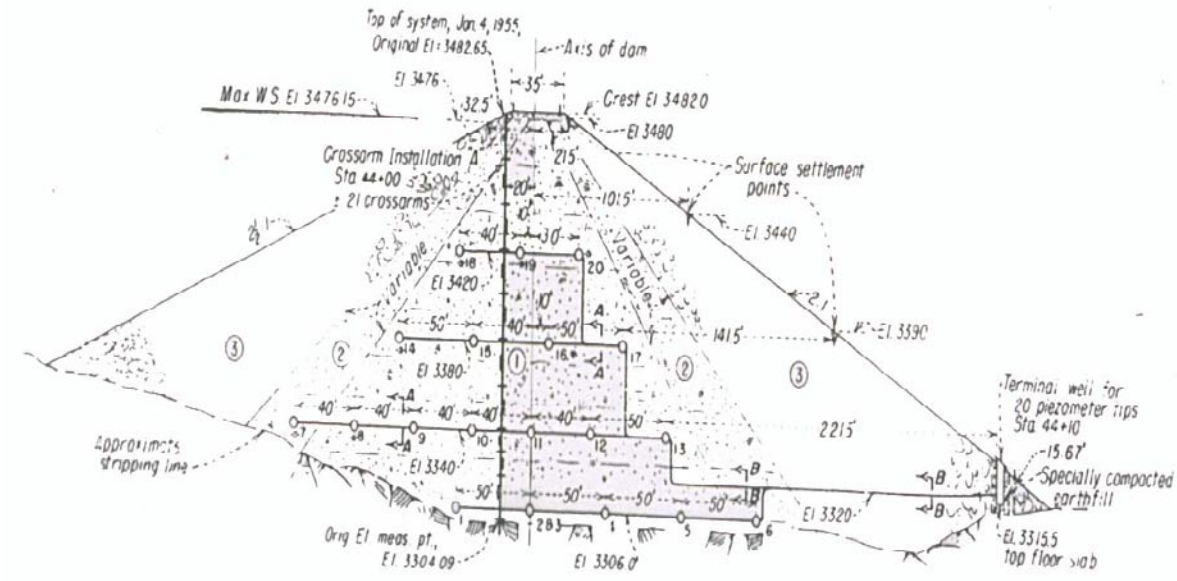

Figure 3.- Typical section of a dam that is instrumented with hydraulic piezometers.

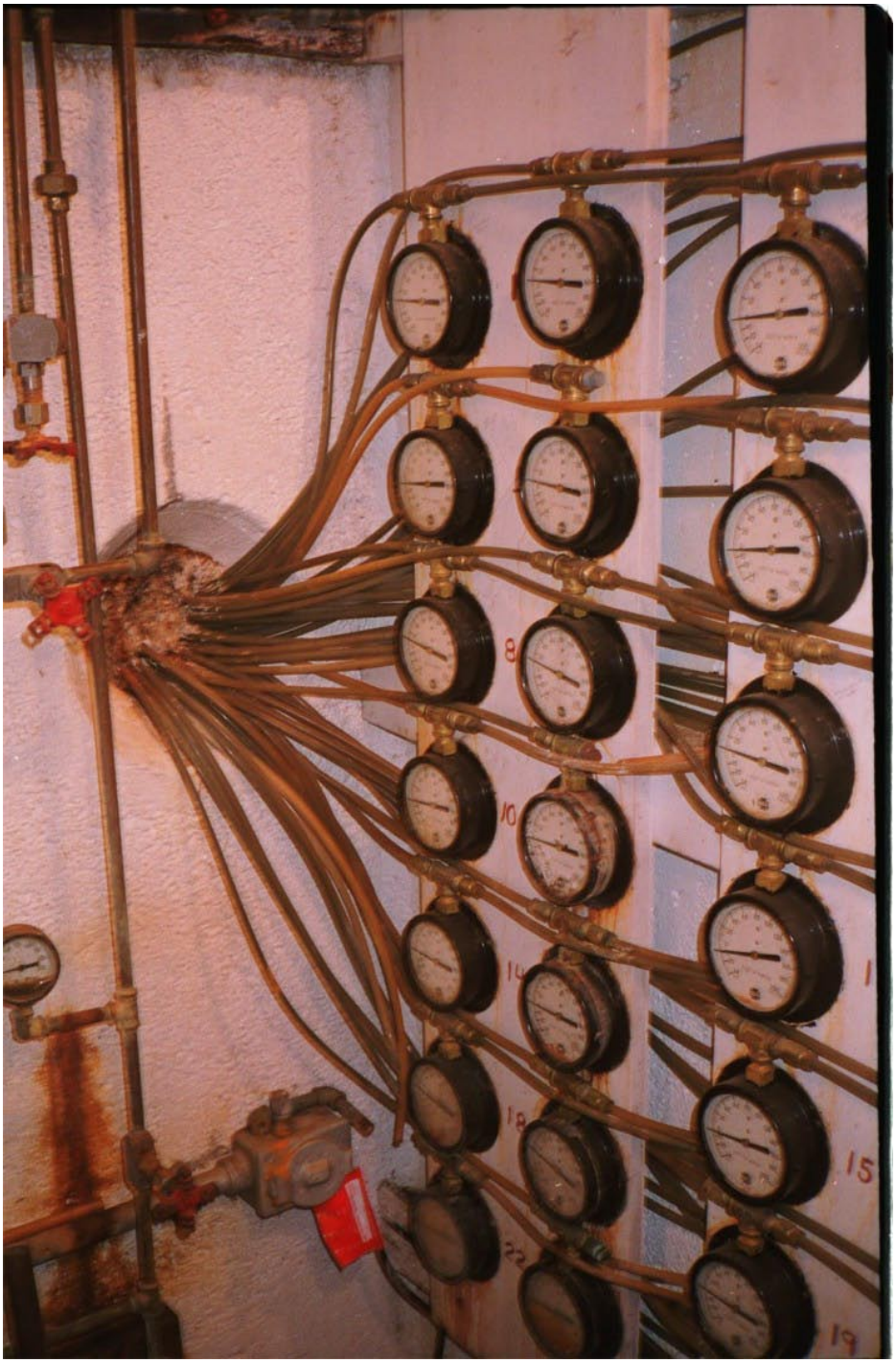

Figure 4.- Photograph of separate gauges in a hydraulic piezometer terminal well. The point of entrance of all the piezometer lines into the terminal well is clearly evident in this photo.

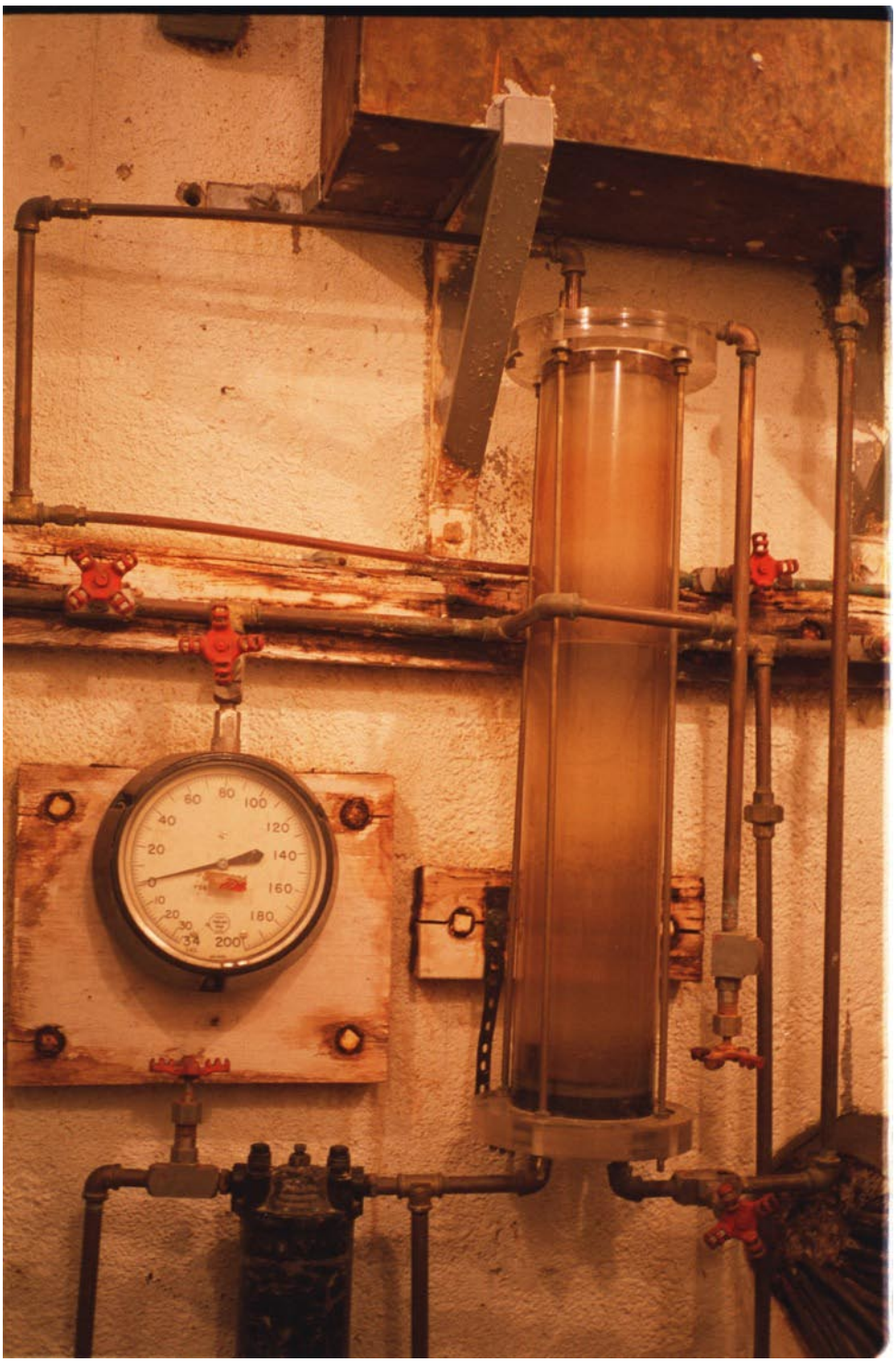

Figure 5.- Photograph of “other equipment” in a hydraulic piezometer terminal well. The master gauge is at left-center. The vertical cylinder air trap is at right-center. The filter unit is at the lower left.

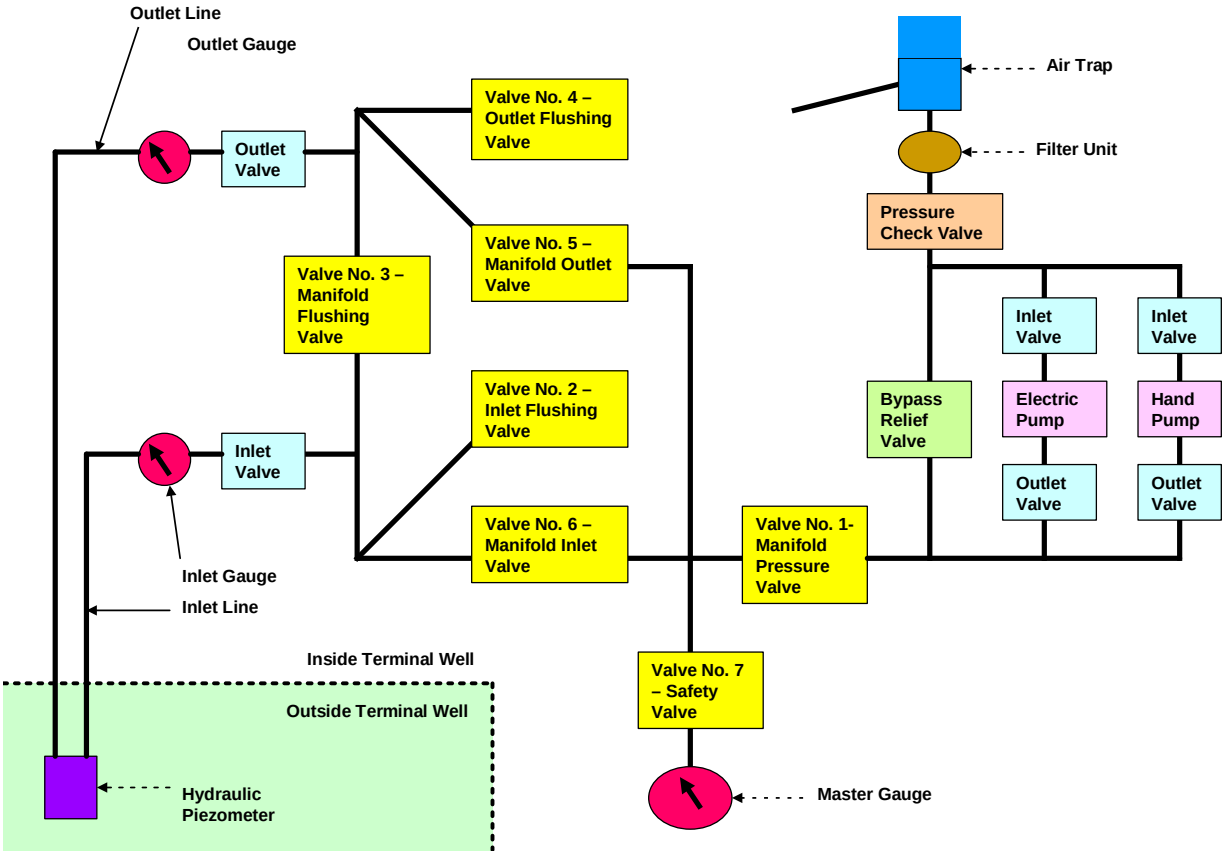

Figure 6.- Schematic view of the equipment and tubing in a typical hydraulic piezometer terminal well installed based on Drawing No. 40-D-4554. Note that the flow direction is from the air trap to the filter unit, then to the pumps, and then to Valve No. 1 (Manifold Pressure Valve).

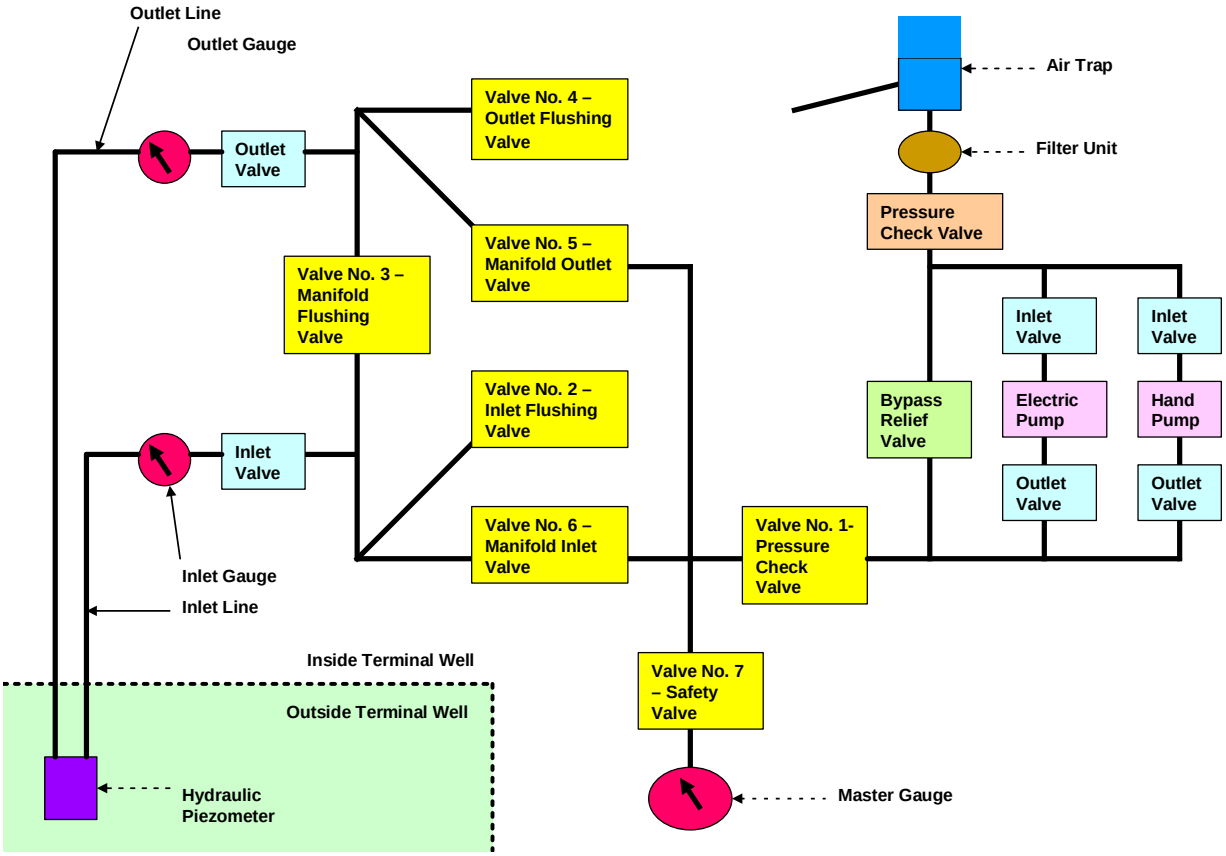

Figure 7.- Schematic view of the equipment and tubing in a typical hydraulic piezometer terminal well installed based on Drawing No. 40-D-4664. Valve numbers have been added in this schematic as no valve numbers are indicated on Drawing No. 40-D-4664. Note that the flow direction is from the air trap to the filter unit, then to the pumps, and then to Valve No. 1 (which is called "Pressure Check Valve" on this figure, but is called "Manifold Pressure Valve" on Figures 6 and 8, based on Drawing Nos. 40-D-4554 and -6088, respectively).

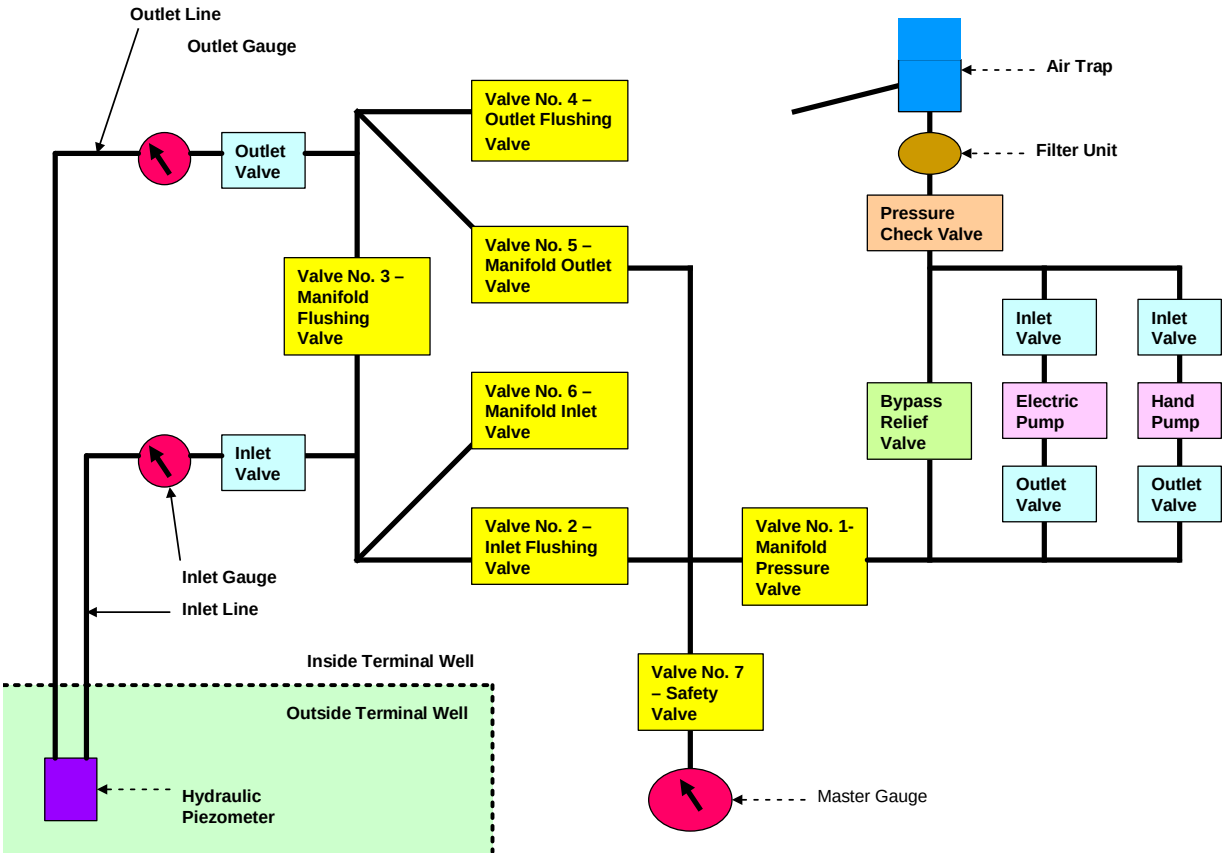

Figure 8.- Schematic view of the equipment and tubing in a typical hydraulic piezometer terminal well installed based on Drawing No. 40-D-6088. It is very important to note that the positions of Valve Nos. 2 and 6 are switched when compared to Figures 7 and 8 (which are based on Drawing Nos. 40-D-4554 and -4664, respectively). Note that the flow direction is from the air trap to the filter unit, then to the pumps, and then to Valve No. 1 (Manifold Pressure Valve).

Appendix A
Reclamation Dams With Hydraulic Piezometer Installations – Summary of Information

Note: Except where otherwise noted, all active terminal wells were installed based on the details shown on Drawing No. 40-D-4554.

Dam Name	Region	Number and Status of Terminal Wells	Tubing Type
*Anderson Ranch	PN	1 Active	Saran Plastic
Arthur V. Watkins	UC	1 Inactive, and 4 Destroyed	Saran Plastic
B.F. Sisk (San Luis)	MP	2 Inactive	Saran Plastic
Bonny	GP	2 Active and 1 Inactive	Tenite II Plastic
Boysen	GP	1 Inactive	Tenite II Plastic
Bradbury	MP	1 Destroyed	Saran Plastic
Carter Lake	GP	1 Active	Saran Plastic
Cedar Bluff	GP	1 Active and 1 Inactive	Tenite II Plastic
Crawford	UC	1 Active	Saran Plastic
Davis	LC	1 Inactive	Tenite II Plastic
Deer Creek	UC	2 Destroyed	Copper
Dixon Canyon	GP	1 Destroyed	Tenite II Plastic
Emigrant	PN	1 Inactive	Saran Plastic
Enders	GP	1Active and 1 Inactive	Tenite II Plastic
Fort Cobb	GP	1 Active	Saran Plastic
Foss	GP	2 Active	Saran Plastic
Fresno	GP	1 Active and 2 Inactive	Copper
Green Mountain	GP	4 Inactive	Copper

Dam Name	Region	Number and Status of Terminal Wells	Tubing Type
Granby	GP	1 Active	Tenite II Plastic
Heart Butte	GP	1 Active and 1 Inactive	Tenite II Plastic
***Heron	UC	1 Active	Saran Plastic
Horsetooth	GP	1 Destroyed	Tenite II Plastic
Jackson Gulch	UC	1 Inactive (and Inaccessible - Backfilled)	Tenite II Plastic
Keyhole	GP	1 Inactive	Saran Plastic
Kirwin	GP	1 Active	Polyethelene Plastic
Lovewell	GP	2 Active	Polyethelene Plastic
Medicine Creek	GP	1 Active and 1 Inactive (and Inaccessible – Backfilled)	Tenite II Plastic
Merritt	GP	1 Inactive	Saran Plastic
*Navajo	UC	1 Active	Saran Plastic
North	PN	1 Inactive	Tenite II Plastic
O'Sullivan	PN	1 Active	Tenite II Plastic
Palisades	PN	1 Active	Polyethelene Plastic
Pinto	PN	1 Active and 1 Inactive	Tenite II Plastic
Red Willow	GP	1 Active	Saran Plastic
**Sanford	GP	1 Active	Impolene Plastic
***Scoggins	PN	1 Active	Impolene Plastic
Senator Wash	LC	1 Inactive	Saran Plastic
Sherman	GP	1 Active	Saran Plastic
Shadehill	GP	1 Active	Tenite II Plastic

Dam Name	Region	Number and Status of Terminal Wells	Tubing Type
Sly Park	MP	1 Active	Polyethelene Plastic
Soldier Canyon	GP	1 Destroyed	Tenite II Plastic
Spring Canyon	GP	1 Destroyed	Tenite II Plastic
Steinaker	UC	1 Destroyed	Saran Plastic
***Sugar Pine	MP	1 Active	Polypropylene Plastic
Tiber	GP	1 Active	Polyethelene Plastic
Trenton	GP	1 Active	Tenite II Plastic
**Trinity	MP	1 Active	Saran Plastic
Twitchell	MP	1 Inactive	Polyethelene Plastic
Vallecito	UC	1 Active and 1 Inactive	Copper
Wickiup	PN	1 Inactive	Copper

* Consult SOP and/or construction drawings for installation details as this is a non-standard installation.

** Installed based on Drawing No. 40-D-4664.

*** Installed based on Drawing No. 40-D-6088.

Appendix B
Recommended Procedures for Abandoning Hydraulic Piezometer Terminal Well Installations

February 29, 1996

To: Files

From: Jay Stateler, Technical Specialist
Structural Behavior and Instrumentation Group

Subject: Abandonment of Hydraulic Piezometer Terminal Well Installations - Recommended Procedures

A meeting was held on February 23, 1996, relative to the noted subject, involving the following people:

John Cyganiewicz	Group Manager, Geotechnical Engineering Group 1
Bill Engemoen	Group Manager, Geotechnical Engineering Group 2
Perry Hensley	Group Manager, Geotechnical Engineering Group 3
DeWayne Campbell	Group Manager, Structural Behavior and Instrumentation Group
Jay Stateler	Technical Specialist, Structural Behavior and Instrumentation Group
Chuck Redlinger	Civil Engineer, Dam Safety Program Office

The following conclusions were reached relative to abandonment of hydraulic piezometer terminal wells (when no future need for monitoring <u>any</u> of the piezometers terminated in a well is seen):

1. Currently available grouting materials and methods are such that grouting of abandoned piezometer lines is <u>not recommended</u>. Factors associated with this conclusion include: (a) the potential for introducing grout into the embankment at elevated pressures, thereby causing harm to the embankment, (b) the recognition that grouting of piezometer lines using current materials and methods will preclude future grouting using potentially superior products and approaches, (c) the availability of results from a State of California study that recommended against such grouting using currently available products and methods, and (d) the concurrence of Reclamation grouting experts in the Materials Engineering and Research Laboratory Group with this conclusion. If future rigorous testing and analysis of newly developed grouting materials and/or methods shows that

this work can be performed effectively at low risk, it would be appropriate to revisit the current "do not grout" recommendation.

2. Grouting of hydraulic piezometer lines would be desirable, but only if it could be performed at low risk and high anticipated effectiveness. Such grouting could remove the potential for the following:

> a. The introduction of high water pressures into downstream areas of the embankment, through breaks in the tubing in the downstream areas.
>
> b. The transport of embankment materials into piezometer tubing by seepage flow, through breaks in the tubing, and then deposition of the material inside the terminal well via flow passing through another tubing break in the same line that exits within the terminal well.

3. To limit the potential for the scenario described in 2.b. above, any piezometer tubing that is allowing flow to exit through a tubing break into a terminal well should be promptly repaired. The repair need not be elaborate or elegant, but simply needs to be sufficient to stop current and future seepage flow at that broken piezometer line.

4. Monitoring for seepage at the tube bundle entrance location in the terminal well (following the outside of the piezometer tubes into the well) should be routinely performed. If seepage is observed, effective monitoring for materials transported by the seepage should be promptly instituted and routinely performed. An appropriate method for monitoring for sediments would be to install a "catch basin" below the tube entrance location. The catch basin would be positioned and installed such that all seepage entering the well at the tube bundle location is collected into the basin. The basin would serve as a settling basin where any sediments in the flow would settle out and be collected in the bottom of the basin. The flow from the basin would be discharged at or near the top of the basin so that any sediments would not carried away by the flow.

5. Consideration was given to recommending that an appropriate filtering sand be placed in terminal wells to be abandoned to remove the potential for seepage flows to transport embankment materials into an abandoned well. This approach has the advantage that the scenario described in 2.b. above would not be a threat, and would not rely on timely human intervention to remove the threat (by making repairs to broken lines in the terminal well). Also, it would be a reversible decision, in that the sand could be removed relatively easily in the future if new conditions/information warranted this be done. However, placing filtering

sand in abandoned terminal wells is not recommended for the following reasons:

a. The scenario described in 2.b. above is not considered to be a significant risk due to the small diameter of the piezometer tubes (3/16-inch inside diameter), and the consequent low likelihood that material transport could occur for an extended period of time without "plugs" in the line developing naturally.

b. If seepage with material transport were to develop inside or along the outside of a piezometer tube, the filter sand in the terminal well should cause the transported materials to be deposited where the flow first encountered the filter material. This in time would lead to plugging off of the seepage route, which would divert the flow to some other exit location. Therefore, where seepage with material transport is occurring along a discreet, "narrow" path, filtering of the flow occurs for only a limited period of time, until the path becomes plugged off.

c. If seepage without material transport were to develop inside or along the outside of a piezometer tube, placing filter sand in the terminal well could raise the water pressures at all points within the embankment along the seepage path (when compared to a terminal well without filter sand).

d. By placing filter sand in the terminal well, access into the well obviously would be lost to observe actual conditions, and to repair tubing breaks within the terminal well. In fact, placing the sand in the terminal well likely would cause some new tubing breaks in the well. If more than one piezometer had a tubing break, then the sand-filled terminal well could provide a means for a piezometer with a broken line in the terminal well to raise the water pressure in the terminal well, and then "back-pressure" other piezometers with broken lines that reside in lower pressure areas of the embankment.

Though not recommended as an <u>initial</u> course of action when abandoning a terminal well, placing sand in an abandoned well remains an option if future problems develop relative to material transport with seepage flows.

Appendix C
Technical Paper: "Creation of Seepage Paths of Concern by Deteriorated Hydraulic Piezometer Installations"

CREATION OF SEEPAGE PATHS OF CONCERN BY
DETERIORATED HYDRAULIC PIEZOMETER INSTALLATIONS

by
Jay N. Stateler, Bureau of Reclamation
U.S. Department of the Interior

Note: A version of this paper was presented at the 19th USCOLD Annual Meeting and Lecture, May, 1999, in Atlanta, Georgia.

ABSTRACT

The presence of hydraulic piezometers in embankment dams creates the potential for seepage-related failure modes due directly to their associated tubing. Since the tubing may deteriorate with age, the potential for problems increases with time. Therefore, the dam safety risks associated with these installations need to be appropriately managed. The potential failure modes need to be clearly defined so that they are well understood by all involved, and so that an appropriate monitoring program can be defined. Even if hydraulic piezometer installations are abandoned, potential failure modes still exist. Several special circumstances associated with hydraulic piezometers make the risk of dam safety problems associated with them greater than for other piezometer types used in embankment dams. This paper draws upon the experience of the Bureau of Reclamation (Reclamation) in operating and maintaining hydraulic piezometer installations at 50 embankment dams.

INTRODUCTION

During construction of an embankment dam, it may be painful for design and construction personnel to observe trenches being cut through the embankment, in an upstream/downstream orientation, to accommodate an array of water pressure monitoring instruments and their associated cabling or tubing. The well-compacted impervious embankment is being dug out and replaced with a construction anomaly that could create a potential lower-resistance seepage path!

Typical construction practice for such instrument trenches includes periodic bentonite plugs along the trench, excavated a distance into the sides and bottom of the trench, to provide a reliable obstruction to seepage in the trench. However, seepage-related concerns continue to exist due to the piezometer installations, and rightly so, particularly as the dam ages.

Figure 1 shows a typical array of hydraulic piezometers in a Bureau of Reclamation (Reclamation) embankment dam. Some of the piezometers are

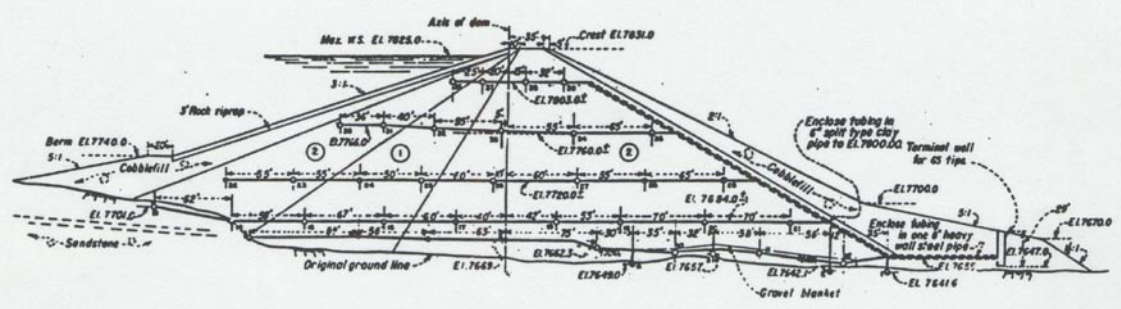

Figure 1: Typical Array of Hydraulic Piezometers in an Earth Dam

installed in the dam foundation in drill holes, while the majority of the piezometers are installed within the dam embankment itself. The twin tubes associated with each instrument are run to a terminal well at the downstream toe of the dam (where readings are obtained) principally through horizontal trenches in the dam embankment, though the tubes also do make vertical or sloped runs to accommodate elevation changes needed to reach the terminal well. Hydraulic piezometers pose special seepage risks, beyond those posed by other water pressure monitoring instruments, for the following combination of reasons:

1. The tubes are actually small water-filled plastic pipes, typically about 1/4 inch in diameter, that have the capability to effectively transport water through them (including seepage water). Electrical cables associated with vibrating-wire, Carlson-type, or other electrically-based piezometers do not offer a "ready-made" seepage path within them as their interior space is filled. Pneumatic piezometers use tubing, and therefore also do offer an "interior seepage path", though for actively used pneumatic piezometers, the presence of any significant amount of water within the tubing quickly becomes obvious during reading of the instruments.

2. The hydraulic piezometer terminal well must be located at a low elevation at the downstream toe of the dam so that positive (or nearly positive) water pressure exists in all the tubes within the terminal well, where the water pressure is measured by Bourdon-type pressure gauges. Slight negative water pressures can be tolerated at the well, but

excessively negative pressures (more than one atmosphere) cannot be accommodated as valid readings will not be obtained. With the terminal well so located, it means that some of the hydraulic piezometer tubes run from upstream portions of the dam embankment (perhaps upstream of the core) all the way to the downstream toe of the dam, affording a seepage path essentially through the entire dam embankment. By contrast, pneumatic piezometers and electrically-based piezometers can have their readout location anywhere in the vicinity of the piezometers, with no operational restriction on the elevation of the readout location. Consequently, these installations do not typically provide such long (potentially low-resistance) seepage paths that traverse much or most of the upstream/downstream distance through the dam.

3. The use of hydraulic piezometers in Reclamation dams dates back to approximately 1940. Materials initially used for tubing proved to become brittle with age, increasing the potential for tubing breaks. The use of pneumatic piezometers in dams began decades later and the materials selected for use in tubing benefitted from the lessons learned over the years, including the hydraulic piezometer experience. Consequently, at this time the potential for problems associated with breaks in hydraulic piezometer tubes is significantly greater than for pneumatic piezometer tubing.

Given the special risks posed by hydraulic piezometers, due to the above factors, they will be the focus of this paper.

POTENTIAL FAILURE MODES

The Bureau of Reclamation has 50 embankment dams that have one or more sections of hydraulic piezometers installed in them. To assess the risks posed by these installations, it is first useful to identify the potential failure modes associated with them.

Failure Mode 1 -- Illustrated Schematically in Figure 2

A break in a hydraulic piezometer tube is present within the impervious portion of the dam embankment, and a break is also present in the same tube within the hydraulic piezometer terminal well. The portion of the tubing between the two break points serves as a very low resistance seepage path that has no filter protection against transport of embankment material by the seepage flow. Seepage through the dam enters the tubing at the upstream break point, carrying with it embankment material. The seepage exits into the terminal well, and then exits the terminal well through a floor drain typically provided in these wells. The seepage then flows into coarse cobblefill or rockfill that often is present around terminal

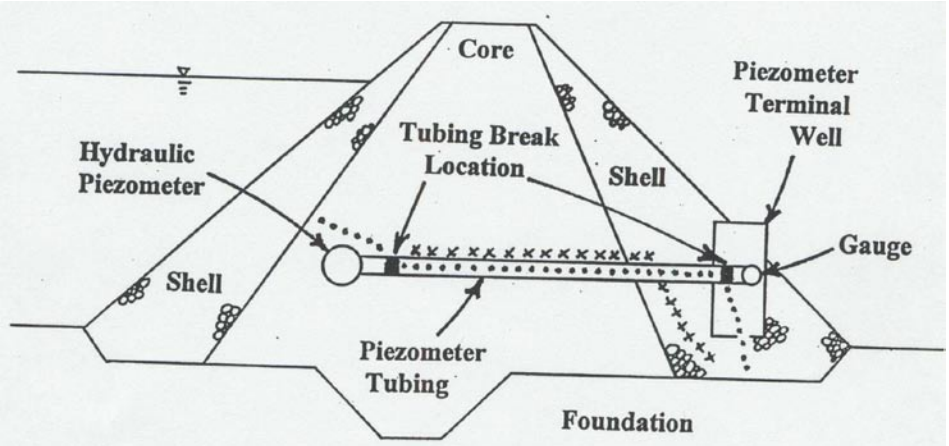

Figure 2: Failure Mode 1 Seepage Path Schematic
Initial Seepage Path: • • • • • • • • •
Ultimate Seepage Path: × × × × × × ×

wells. There is no location along this seepage path where material transport by the flow would be prevented. Removal of embankment material would progress from the upstream tubing break location toward the reservoir. Eventually, when a large "pipe" had formed, the flow quantities would overwhelm the capacity of the tube downstream of the upstream break location, so new seepage paths downstream of this break would develop (potentially following the outside of the tube initially) as the situation progressed toward a breach of the dam and catastrophic failure.

In the event that the terminal well is not surrounded by pervious material, such as cobblefill or rockfill, and a low resistance seepage exit path is not available from the terminal well, then an impediment to the possible development of this failure mode exists. Usually the floor drain provided in the well is designed to provide effective drainage, but in the event it does not, the initial seepage path could only remove a relatively small volume of embankment material (say 1 to 5 yd^3) before a rise in water pressures in the terminal well would prevent further flow and material transport into the well. However, it is possible that the removal of this quantity of material could set in motion a process whereby an alternate seepage path (through the embankment) develops downstream of the upstream break in the tube, allowing a resumption of progression of the failure mode toward eventual dam failure.

Failure Mode 2 -- Illustrated Schematically in Figure 3

Seepage flow occurs along the outside of the hydraulic piezometer tubing, following a lower resistance seepage path created by the construction

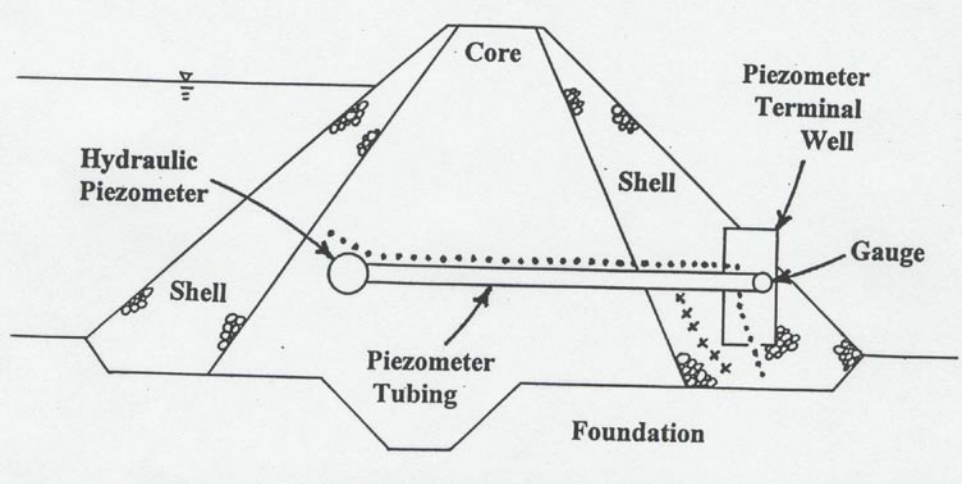

Figure 3: Failure Mode 2 Seepage Path Schematic
Initial Seepage Path: • • • • • • • • •
Ultimate Seepage Path: × × × × × × ×

anomaly associated with providing the hydraulic piezometers and tubing. Flow enters the terminal well at the tube bundle inlet, and then proceeds out of the well as described above relative to Failure Mode 1. Progression of the failure mode is by backward erosion of embankment material by seepage flow from the terminal well towards the reservoir, following along the tubing path during at least the initial portions of development of the failure mode. Eventually the "pipe" would reach the reservoir and a breach would develop that would lead to catastrophic dam failure.

Failure Mode 3 -- Illustrated Schematically in Figure 4

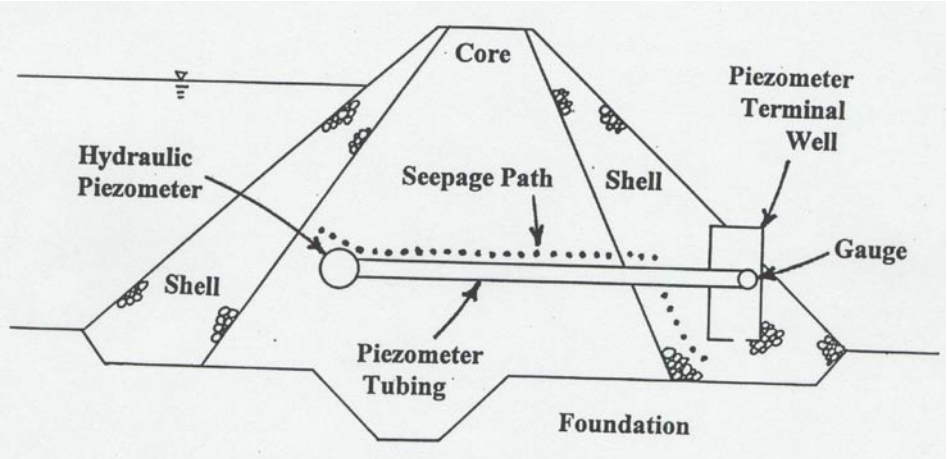

Figure 4: Failure Mode 3 Seepage Path Schematic

This failure mode is similar to Failure Mode 2, except that the downstream end of the seepage path does not involve the terminal well. Seepage flow

occurs along the outside of the hydraulic piezometer tubing, but exits into coarse downstream shell material once it gets out of the "impervious" portion of the dam embankment. As with Failure Mode 2, progression of this failure mode is by backward erosion of embankment material by seepage flow from the shell zone towards the reservoir, following along the tubing path during at least the initial portions of development of the failure mode. Eventually the "pipe" would reach the reservoir and a breach would develop that would lead to catastrophic dam failure.

Failure Mode 4 -- Illustrated Schematically in Figure 5

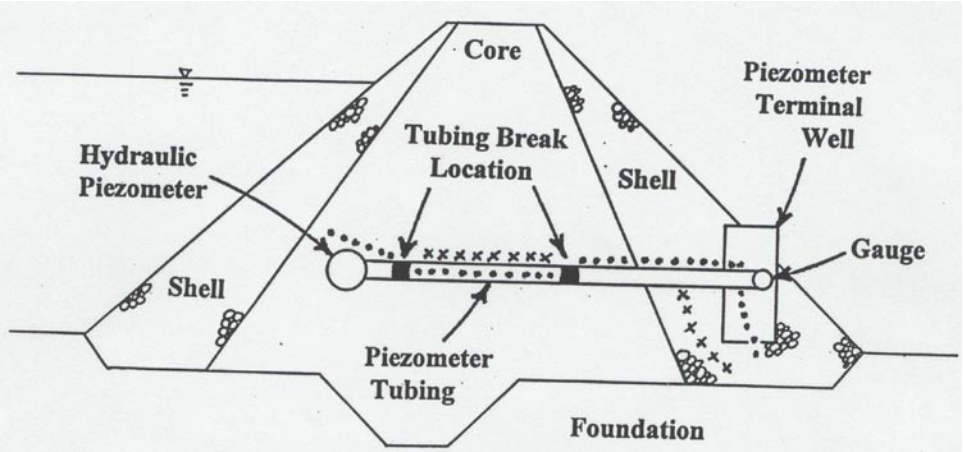

Figure 5: Failure Mode 4 Seepage Path Schematic
Initial Seepage Path: • • • • • • • • • • •
Ultimate Seepage Path: x x x x x x x

This failure mode represents a combination of Failure Modes 1 and 2 above. At least two breaks are present along one tube, but neither break is within the terminal well. The breaks allow seepage flow through the dam to bypass at least a portion of the "impervious" core of the embankment. This creates higher hydraulic gradients upstream of the upstream break and downstream of the downstream break, making material transport by the seepage flow more likely. Downstream of the downstream break, the flow follows the tubing into the terminal well, and the remainder of the seepage path is as described for Failure Mode 1 above. Most likely, progression of the failure mode would be by backward erosion of embankment material by seepage flow from the terminal well towards the reservoir, following along the tubing path for most of the way. Eventually the "pipe" would reach the reservoir. Then larger flows would occur than the tubing portion of the seepage path could handle, so additional paths outside the tubing would develop and eventually a breach would occur that would lead to catastrophic dam failure.

It is also possible that material transport by the seepage flow could initiate in the area upstream of the upstream break. However, for the failure mode to fully develop, the upstream erosion would need to lead to a situation where backward erosion from the terminal well would also be initiated. This is very possible, however, as removal of material upstream of the upstream break would eventually lead to a higher hydraulic gradient in the area downstream of the downstream break, which could cause backward erosion to start there.

Failure Mode 5 -- Illustrated Schematically in Figure 6

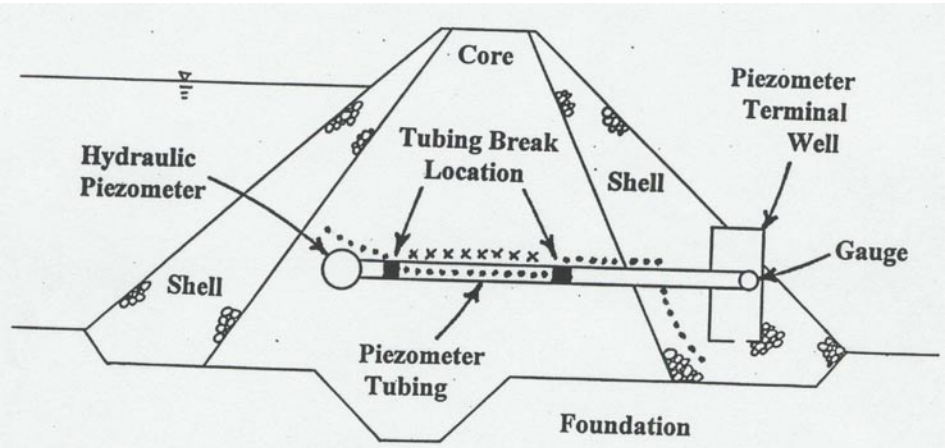

Figure 6: Failure Mode 5 Seepage Path Schematic
Initial Seepage Path: • • • • • • • • •
Ultimate Seepage Path: x x x x x x x

This failure mode is pretty much the same as Failure Mode 4 above, except that the downstream seepage path does not involve the terminal well, but instead the exit point is into coarse shell material. Aside from this difference, the discussion in Failure Mode 4 applies to this failure mode as well.

Failure Mode 6 -- Illustrated Schematically in Figure 7

This failure mode is similar to Failure Mode 4, except that only one break is present in the tubing, so flow upstream of the break location is entirely within the piezometer tubing (from the piezometer tip to the break) when the failure mode initiates. The break occurs in the impervious portion of the dam embankment and allows the higher water pressures present at the piezometer tip location to be injected into the embankment at the break location. This creates a high hydraulic gradient in the impervious material downstream of the break location, which causes backward erosion along the tubing to initiate, beginning at the terminal well and working its way to the break location. Once the "pipe" reaches the break location, a very low

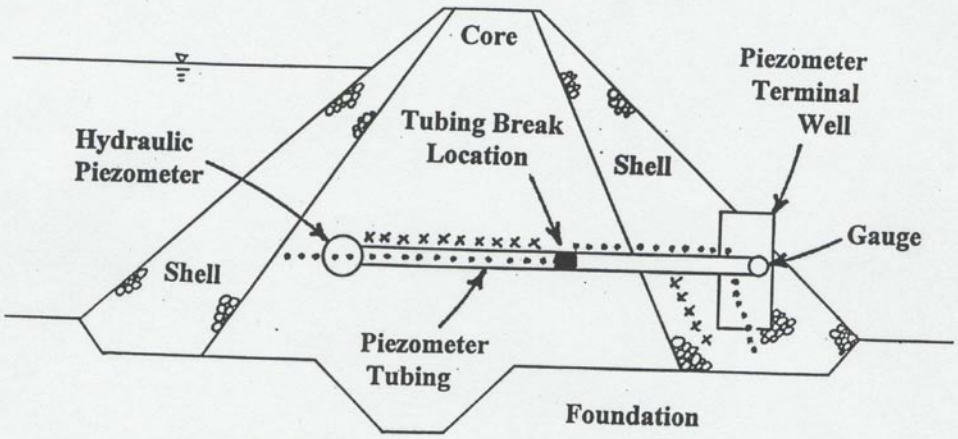

Figure 7: Failure Mode 6 Seepage Path Schematic
Initial Seepage Path: • • • • • • • •
Ultimate Seepage Path: x x x x x x x

resistance seepage path exists from the piezometer tip all the way to the downstream toe of the dam. Consequently flow volumes along the path get large, enlarging the pipe that exists downstream of the break. Eventually this large downstream pipe leads to removal of embankment material upstream of the break location, and the "pipe" works its way upstream towards the reservoir, until finally it reaches the reservoir. A breach would then develop and catastrophic failure would occur.

Failure Mode 7 -- Illustrated Schematically in Figure 8

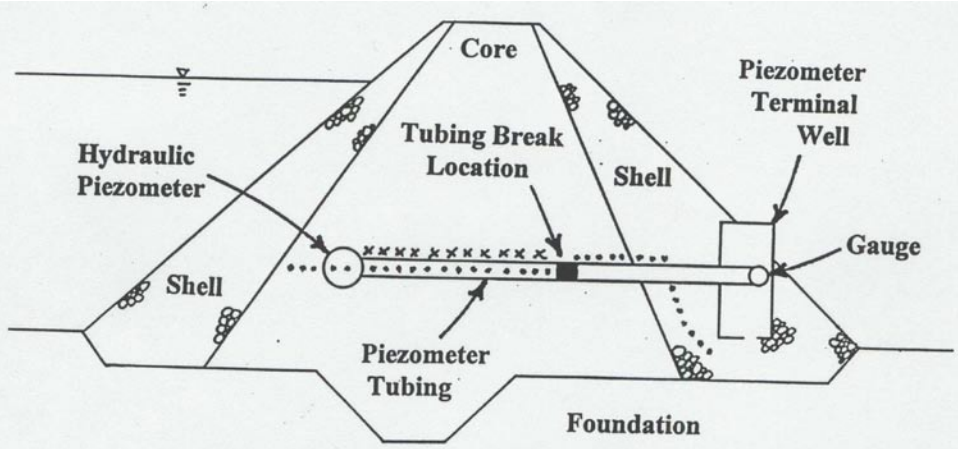

Figure 8: Failure Mode 7 Seepage Path Schematic
Initial Seepage Path: • • • • • • • •
Ultimate Seepage Path: x x x x x x x

This failure mode is essentially the same as Failure Mode 6 above, except that the downstream seepage path does not involve the terminal well, but

instead the exit point is into coarse shell material. Aside from this difference, the discussion in Failure Mode 6 applies to this failure mode as well.

The above seven failure modes represent the scenarios of concern regarding "intact" hydraulic piezometer systems. Whether all these failure modes are relevant to a particular dam requires careful study of design and construction information for that dam. For hydraulic piezometer systems that have been abandoned, some additional considerations apply, depending on what alterations to the system have occurred since abandonment.

If the terminal well was backfilled with concrete, impervious embankment material, or other impervious material, seepage paths through the terminal well are obstructed, meaning that Failure Modes 1, 2, 4, and 6 are no longer possible. However, this is not necessarily good news. If a failure mode must initiate, it would be better if its flow path involved the terminal well, as it would be much easier to detect the developing problem, since conditions in the terminal well could be more readily observed. Shutting off flow into the terminal well would eliminate Failure Mode 1 as a possibility, but could result in transforming developing Failure Mode 2, 4, and 6 situations, which would be readily detectable, into Failure Mode 3, 5, and 7 situations, which would be not be detected as easily.

If the terminal well was backfilled with pervious material, but material that would not effectively filter seepage flow against material transport, then all seven failure modes would still be possible, but the ability to observe development of Failure Modes 1, 2, 4, and 6 would be lost as access to the interior of the terminal well has been lost. This situation obviously is unfavorable.

If the terminal well was backfilled with pervious material that would effectively filter seepage flow against material transport, then again the threat posed by seepage paths involving the terminal well would be eliminated, meaning that Failure Modes 1, 2, 4, and 6 would no longer be possible. Again, on the surface this would seem like good news, but actually this condition ultimately is no better than filling the terminal well with concrete or other impervious material. If seepage flow into the terminal well was attempting to transport material into the well, but was frustrated by filter material in the well, this means that a filter cake would be developing at the upstream face of the filter material. Material carried by the seepage would be deposited on the face of the filter, since it could not get through the filter. As the filter cake got thicker and thicker, more and more head would be required to push the seepage flow through the filter cake. This means that water pressures would be building up in front of the filter, and the filter would be acting more and more like an impervious membrane. Eventually the elevated pressures would result in the seepage finding an alternative path that did not involve the terminal well. Again, eliminating the potential for flow to carry

material into the terminal well would eliminate Failure Mode 1 as a possibility, but could result in transforming developing Failure Mode 2 , 4, and 6 situations, which would be readily detectable, into Failure Mode 3, 5, and 7 situations, which would be not be detected as easily.

MANAGING THE DAM SAFETY RISKS

With this theoretical framework in place regarding potential failure modes, it is now possible to confront three key issues associated with deteriorating hydraulic piezometer installations and the dam safety risks that they pose:

1. What situations pose the greatest risks?

2. What routine monitoring should be performed concerning hydraulic piezometer installations to appropriately manage the dam safety risks posed by them?

3. In the event that it is decided to abandon a hydraulic piezometer system, what actions would be appropriate?

These three issues will be discussed below:

Issue 1: What situations pose the greatest risks?

Some factors to consider in assessing the risks posed by the hydraulic piezometer installations at a particular dam are presented below:

1. Tenite II plastic tubing (cellulose acetate butyrate) and Saran plastic tubing (polyvinyl chloride) have shown increasing brittleness with age, so the risks of tube breaks where these materials were used for the piezometer tubing would be higher than for other tubing types.

2. If the embankment core material is clayey in nature, with a reasonably high plasticity index, then it would be less erodible by seepage flow than would be a silty core material, and consequently the risks of a problem developing would be lower.

3. If an embankment zone is provided immediately downstream of the dam's core that meets current filter criteria with the core material, the potential for development of all the failure modes except Failure Mode 1 would be eliminated, and the potential rate of development of Failure Mode 1 would be severely restricted. Conversely, if the embankment zone immediately downstream of the dam's core is a coarse, open rockfill, then the risk of development of all the failure modes is significantly increased.

4. Large settlements of an embankment dam can increase the stresses on the piezometer tubing, particularly at the more vulnerable transition points between horizontal tubing runs and vertical or sloped tubing runs, and therefore increase the chances for tube breaks.

5. Installing piezometer tube bundles within metal pipes that are left in place at one or more locations within the dam embankment creates the opportunity for shearing of many tubes at one spot in the event of significant differential displacements in the area. Such multiple shears create the potential for apparent or actual "cross connection" of piezometer tubes.

6. Effective bentonite plugs installed periodically along tubing trenches, and extending a distance into the sides and bottom of the trench, essentially eliminates the potential for Failure Modes 2 and 3, and decreases the risks associated with most of the other failure modes.

7. Ongoing seepage into the hydraulic piezometer terminal well at the tube bundle entrance location increases the potential for development of Failure Modes 2, 4, and 6. However, all the failure modes are still possible, even if such seepage is not observed at any particular point in time. Often, seepage into the well is due to local groundwater levels rather than due to seepage through the embankment, so the presence or lack of such seepage is not a particularly good indicator of the relative risk involved.

8. Unusual data collected during annual flushing of the hydraulic piezometer system could be indicative of tubing breaks, and therefore would indicate greater potential for development of a failure mode. This topic will be discussed further relative to "Issue 2".

9. The potential rate of development of Failure Modes 6 and 7 would be much slower if the piezometer had a high-air-entry porous filter, which would significantly limit the flow rate through the piezometer, rather than a low-air-entry filter. Therefore, the risks of catastrophic dam failure would be decreased. The porous filters at the piezometer tips allow transmission of water and water pressure into the piezometer from the surrounding embankment, but prevent transmission of embankment materials into the piezometers.

Beyond information that can be gathered during annual flushing work, the California Department of Water Resources (DWR) has developed an Electro-Conductivity (EC) Test designed specifically to identify breaks in piezometer tubing at a particular installation. Obviously, performing this test will allow the extent of the problems (and risks) to be more accurately assessed. The test is

performed as follows:

1. Each piezometer is first completely flushed with distilled water, so that after flushing, only distilled water, which has very low EC, is in the inlet and outlet tubing at all locations.

2. Thirty days are allowed to pass. During this period, higher EC seepage water can enter the tubing at the piezometer tip, and, more importantly, between the tip and any breaks in the tubing. Since a pressure differential would exist between the tip location and a break location, seepage water would flow through the tubing between these points, completely replacing the low EC distilled water with higher EC seepage water.

3. The system is slowly flushed, and EC values of the fluid being pushed out are measured and recorded. Knowing the tube diameter, the location corresponding to the fluid being collected can be calculated. The location of breaks in the tubing can be determined as one end of a high EC "plateau" (with the tip location being at the other end). Figure 9 shows an illustration of this data.

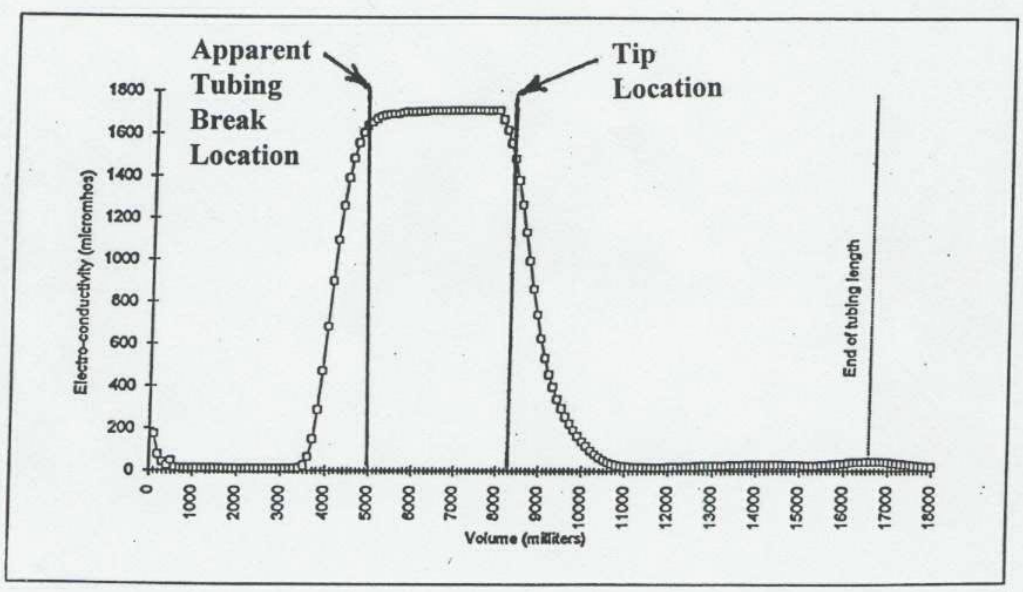

Figure 9:
Sample Data from an Electro-Conductivity (EC) Test of a Hydraulic Piezometer

The EC test obviously is not cheap, both in performance and in data analysis. Often data that is much more ambiguous than that shown in Figure 9 is obtained for some instruments, so the results are not always clear cut. However, the data provided allow a much better understanding of the situation and consequent risks.

Issue 2: What routine monitoring should be performed concerning hydraulic piezometer installations to appropriately manage the dam safety risks posed by them?

Relative to Failure Modes 1, 2, 4, and 6, where the seepage path involves the terminal well, the answer is obvious. Every terminal well needs to be regularly entered and checked for evidence of seepage at the tube bundle entrance location, and leakage from the tubing, valves, etc. within the well. This typically can be readily accomplished at the same time piezometer readings are obtained. A monitoring frequency of at least once every 3 months would be acceptable in low risk situations. More frequent monitoring would be appropriate where risks are higher. Obviously any evidence of material transport by such seepage or leakage would be a serious development and would require an immediate technical evaluation. Leakage within the terminal well from tubing, valves, etc. should be promptly addressed to stop the leakage. Where significant seepage is observed at the tube bundle entrance location, this seepage needs to be regularly monitored for sediment transport by collecting the seepage into a "catch basin" that would trap sediments, or by other comparable means that provide continuous monitoring such that sediments present at any time in the flow would be trapped for future viewing. Flow rate monitoring should also be performed to determine if the situation is changing with time.

One complication associated with visual monitoring for sediments in a hydraulic piezometer terminal well is that sometimes iron bacteria will grow, due to the presence of some seepage into the well. It can be difficult to determine if sediments from the embankment are mixed in with the iron bacteria "ooze". Sampling and lab testing may be necessary. It is important that samples are kept cool in transit to the lab so analysis of the organic material in the sample can be effectively performed.

Relative to Failure Modes 3, 5, and 7, where the seepage path would not involve the terminal well and seepage would exit in the downstream toe area of the dam, the key monitoring activities would be:

1. Monitoring of existing seepage and drain flows in the toe area for evidence of material transport by the flow, and for flow rates not in line with historical performance.

2. Visual monitoring of the toe area for new seepage or wet areas, or unusual changes at existing seepage or wet areas. Obviously, any evidence of material transport at seepage or wet areas would be a key visual monitoring issue.

3. Monitoring of water pressures recorded at the hydraulic piezometers for unusual behavior. Since the flow paths of concern are adjacent to these

piezometers, they could give an indication of a developing problem. Unusual drops in water pressures at instruments near the downstream toe of the impervious portion of the embankment could be an indication that a piping failure mode has initiated.

4. Visual monitoring for unusual depressions or settlements above the downstream portion of the impervious portion of the embankment (due to subsurface removal of material by piping). This monitoring makes theoretical sense, but practically speaking, it would be a much less effective monitoring approach for these failure modes than the three items listed above. Nonetheless, awareness of the possible significance of such depressions or settlements is important.

If unusual developments are noted in the course of the above monitoring, they may be due to initiation of Failure Modes 3, 5, and/or 7, but they could also be due to deteriorating seepage performance of the dam unrelated to the hydraulic piezometers. In any event, such observations would warrant a prompt and thorough technical evaluation. Since the above "key monitoring parameters" are not as directly tied to the initiation and development of the failure modes as direct monitoring of the seepage flows into the terminal well, more frequent monitoring of them is needed to allow early detection of a developing failure mode. Therefore, at least monthly monitoring would be appropriate when the reservoir is at least moderately full.

Hydraulic piezometer installations require annual maintenance work involving flushing to remove air from the tubes (which would cause inaccurate data) and to remove organic growth from the tubes (which could lead to plugging of a tube and eventual loss of the associated instrument). The annual maintenance work also involves checks to ensure gauge accuracy (against a master gauge in the well), replacing the cartridge in the water filter unit, and general repair of any tubing leaks, valve leaks, leaks at connections, etc. It is important that when the flushing work is performed, awareness is maintained, and notes are made concerning unusual fluid losses or other unusual occurrences that may indicate tube breaks. It is important to bear in mind, though, that significant fluid loss would be expected for piezometer tips installed in pervious zones of the dam or foundation, as water will flow out the piezometer tip during the flushing work.

Issue 3: In the event that it is decided to abandon a hydraulic piezometer system, what actions would be appropriate?

The central issue relative to this question is whether abandoned piezometer tubing should be grouted. Factors to consider relative to this issue are as follows:

1. If hydraulic piezometer tubes could be completely and effectively grouted, the possibility of Failure Modes 1, 4, 5, 6, and 7 would be

eliminated.

2. Grouting of piezometer tubes that possibly have breaks in them has the potential of introducing grout into the embankment at elevated pressures, which could cause harm to the embankment.

3. Grouting of piezometer tubes using current materials and methods will preclude future grouting using potentially superior products and approaches.

4. The DWR did a study in 1996 that recommended against such hydraulic piezometer tube grouting at Oroville Dam, using currently available products and methods. Grout formulations intensively studied at that time were epoxy resin, acrylic resin, and microfine cement. The acrylic resin was preferable to the epoxy resin and microfine cement, as they both had fatal pumpability problems, but in the end the "no action" alternative was selected.

Reclamation's current technical recommendation on the issue is to not grout the tubes using currently available grouting materials and methods. However, if future rigorous testing and analysis of newly developed grouting materials and/or methods shows that the work can be performed effectively at low risk, then it would be appropriate to revisit this recommendation.

Abandoned terminal wells need to be monitored in the same manner that active terminal wells are monitored, as discussed previously, with the following exception. The annual maintenance work required for active installations (including flushing, gauge checks, etc.) is not necessary, but the monitoring work and leak repair work is equally important as it is for active installations.

Though not recommended as an <u>initial</u> course of action when abandoning a terminal well, placing filtering sand in an abandoned well remains an option if problems develop relative to material transport with seepage flows.

In situations where a hydraulic piezometer terminal will be removed during a dam modification project, the "do not grout" rule can be amended somewhat, as the potential for future improvements in grouting technology becomes irrelevant to the question as the only chance to grout will be during the construction process. Thereafter, no access to the ends of the tubes will exist. Still, Reclamation is not in favor of complete grouting of the tubes using current materials and methods because of concerns about possible damage to the embankment, due to grout leaking out at tube breaks. Sealing of the very end of the tubes is all that is currently recommended.

SUMMARY

The dam safety risks associated with hydraulic piezometer installations in embankment dams need to be appropriately managed. The potential failure modes need to be clearly defined so that they are well understood by all involved, and so that an appropriate monitoring program can be defined. The relative risk of potential failure needs to be roughly understood so that appropriate monitoring frequencies efforts can be established. Several special circumstances associated with hydraulic piezometers make the risk of dam safety problems associated with them greater than for other water pressure monitoring methods used in embankment dams. Deterioration of hydraulic piezometers due to aging increases the risk of failure mode initiation with time. Any evidence of unusual drops in water pressures, material transport by seepage flow, and/or changed seepage performance within or near a hydraulic piezometer terminal well should receive a prompt and thorough technical evaluation.

Appendix D
Annual Maintenance of Hydraulic Piezometer Installations, Including Flusing the Lines and Obtaining Master Gauge Readings, for Terminal Wells Constructed Based on Drawing No. 40-D-6088 (shown schematically on Figure 8)

Note: For nearly all Reclamation hydraulic piezometer terminal wells, the annual maintenance work should be performed as described in Section VI. above. The instructions contained in this appendix apply only to terminal wells constructed based on Drawing No. 40-D-6088 (shown schematically on Figure 8). For these wells, the locations of Valve Nos. 2 and 6 are switched, when compared to all other Reclamation wells. For simplicity in preparing SOPs, this appendix provides complete replacement text for Section VI. above, for those wells constructed based on Drawing No. 40-D-6088. It is believed that this text applies only for wells at Heron, Scoggins, and Sugar Pine Dams.

A. General Overview

The guidance provided in this section supercedes similar guidance provided on this subject in the 1987 Embankment Dams Instrumentation Manual.

The intent of the annual maintenance work, which includes flushing the piezometer tubing and checking the validity of each of the separate gauges, is as follows:

1. Eliminate air from within the piezometer tubing, which, if present, would lead to inaccurate data, as discussed in Section V.

2. Flush out bacterial material from within the piezometer tubing, which, if left unchecked, could grow and potentially plug off the tubing such that the instrument would eventually need to be abandoned as it could not be flushed, and therefore data from it would be suspect.

3. For each individual separate gauge, obtain a reading of it at the same time a master gauge reading is taken, with the same pressurized water acting on both gauges. After correcting for the elevation difference between the two gauges, the readings can be directly compared to determine if the separate gauge is functioning satisfactorily or if it needs to be replaced.

4. Based on the work and results of item 3. above, a correction value can be developed for each separate gauge so that readings from it can adjusted to the "most probable value", using all the information available from the master gauge work performed in the terminal well.

5. Gather important "performance" information about each piezometer installation, learned during the flushing work, and document it for future reference. Typically the information relates to water lost during flushing, and debris and/or air observed at the air trap during flushing. Sometimes, however, more unusual performance takes place during flushing and it is very valuable to document what is observed so that appropriate actions can be taken regarding the piezometer in the future.

The "Annual Maintenance Report Form" (AMRF) has been developed to capture all the key data and information obtained in the course of the annual maintenance work. Copies of this form, customized for the dam where it will be used, are available from D-8460. An example of a blank AMRF is presented in Appendix F, and an example completed AMRF is presented in Appendix G.

B. Detailed Discussion

Whenever annual maintenance work concerning hydraulic piezometer installations in a terminal well is due to be performed, it will be necessary to enter the terminal well a couple times (at least). The first issue is personal safety, so the considerations discussed in Section III. need to be addressed. With safety considerations appropriately addressed, then before beginning the maintenance work, the opportunity should be taken to perform the inspection work described in Section VI. When this work has been completed, one can then proceed with the flushing and master gauge reading activity. The various steps associated with this work are discussed below. The discussion in this section assumes the valves in the terminal well are numbered consistent with what is shown on Figure 8.

1. Preparation Work

a. Obtain a blank "Annual Maintenance Report Form" (AMRF) that has been customized for use at the hydraulic piezometer terminal well in question. If a customized blank AMRF form is not available, D-8460 can be contacted to obtain one. An example blank AMRF is presented in Appendix F and an example completed AMRF is presented in Appendix G.

b. Inspect the cartridge in the water-filter unit and replace it as necessary. It is vital that an effective water-filter unit be present in the hydraulic piezometer system to remove "debris" in the water dislodged by flushing work. A clogged cartridge will reduce the effectiveness of the pumps. In some instances, where the proper replacement cartridge is not on hand nor commercially available

(discontinued product), then it may be necessary to replace the entire water-filter unit so that a serviceable filtering cartridge can be provided. D-8460 can be consulted if problems or difficulties arise in this area.

c. Inspect the air trap unit. If it is made of plexiglass, you should be able to see directly through the air trap and observe the water inside the trap. If you are unable to do this, the trap should be disassembled and thoroughly cleaned. If the air trap is a steel air trap, strong consideration should be given to replacing it with a plastic air trap (available from D-8460), so that monitoring of flushing work (i.e. monitoring the amount of debris and air flushed from the lines) can be effectively performed. If a steel air trap is being used, a sight glass usually is provided with the unit. If this sight glass is dirty such that viewing the water level is difficult, then the steel air trap should be cleaned and the sight glass plastic tubing should be replaced. (Note: cleaning air traps will probably provide the additional benefit of reducing the frequency at which the water filter cartridges will need to be changed.) Clear vinyl scales should be located on the plastic air trap (or sight glass on a steel air trap) so that water level changes during flushing work can be accurately determined. These vinyl scales are available from D-8460.

d. To make sure that an adequate supply of “make-up water" is available during the flushing work, refill the water container (reservoir tank) in the terminal well with piezometer fluid consisting of distilled (or the best available) water to which 4 teaspoons of a 25-percent solution of QAC (Quaternary Ammonium Compound) has been added for each 10 gallons of replacement water. QAC is a bacterial inhibitor and wetting agent used to stop the growth of algae and help the flushing process effectively remove air bubbles. The Material Safety Data Sheet (MSDS) for the active ingredient in the QAC should be made readily available to operating personnel. D-8460 should be contacted if QAC, and the MSDS, is needed.

e. Make sure the electric pump is operable and functioning satisfactorily. While theoretically the hydraulic piezometer annual maintenance work could be accomplished using only a hand pump, this is not recommended. Realistically, an electric pump is needed. Electric pumps are not that expensive and pump replacement should promptly occur when circumstances warrant.

f. If the pressure at any of the separate gauges in the terminal well is negative, a functioning hand pump will be needed, so make sure it is operable and works satisfactorily. If none of the separate gauges shows a negative reading, then a functioning hand pump is not required.

2. Flushing Work Day

a. Preparation work prior to beginning flushing

i. Read and record the inlet and outlet separate gauge readings in column 1 of the

AMRF before starting the flushing work to document the initial conditions.

ii. Check the entire system in the terminal well to ensure that all valves are closed. Close any valves that are not closed.

iii. Open the filler valve and the bleeder valve to the air trap. Fill the air trap with fluid to within 3 inches of the top of the plastic air trap or to the top of the sight glass for a steel air trap. Then close the filler and bleeder valves.

iv. IMPORTANT NOTE: Add fluid to the air trap, to the levels noted in step iii. above, any time during the course of the flushing work that the fluid level in the air trap drops below one-half full.

v. IMPORTANT NOTE: If the SOP for a dam includes site-specific instructions that differ from those presented in this section, follow the SOP instructions.

b. Flushing the manifold lines

i. Open the inlet and outlet valves to the electric pump (or hand pump, if for some reason it is being used).

ii. Open, in sequence, Valve Nos. 2, 3, 4, and 1.

iii. Start pumping and continue flushing this circuit until air bubbles no longer appear at the air trap.

iv. Close, in order, Valve Nos. 1, 4, and 2. (The electric pump may be left running.)

v. Open Valve No. 7, wait three minutes, and then close Valve No. 7. (This is done to allow any air bubbles in the line between Valve No. 7 and the master gauge to move vertically upwards into areas of the manifold lines where they can be removed by flushing performed in the next step.)

vi. Open, in sequence, Valve Nos. 5, 6, and 1 (Valve No. 3 is already open, from Step ii. above). Continue pumping and flush this circuit until air bubbles no longer appear at the air trap. Then close, in order, Valve Nos. 1, 6, 3, and 5.

vii. Open, in sequence, Valve Nos. 2, 6, and 1. Continue pumping and flush this circuit until air bubbles no longer appear at the air trap. Then close, in order, Valve Nos. 1, 6, and 2.

viii. Open Valve No. 7, wait three minutes, and then close Valve No. 7.

ix. Open, in sequence, Valve Nos. 5, 4, and 1. Continue pumping and flush this circuit until air bubbles no longer appear at the air trap. Then close, in order,

Valve Nos. 1, 4, and 5.

c. Flushing the piezometer lines

Before proceeding with this flushing work, the following information should be reviewed:

- Valve No. 1 is used to throttle, or control, the pressure applied during direct and reverse flushing of each piezometer. Valve No. 1 should be opened and closed slowly to prevent surges of pressure when circulating water in the system. Valve No. 1 must be a needle valve, so that the needed throttling can be performed. A ball valve, or a series of ball valves, will not work.

- During direct flushing of a piezometer (water is being pumped into the inlet line and returning through the outlet line), the inlet gauge reading should exceed the corresponding AMRF column 1 value for the inlet gauge by approximately 30 feet. This provides sufficient pressure to create suitable flow through the piezometer line, yet avoids the introduction of excessive pressures into the dam embankment or foundation at the piezometer due to the flushing work. During direct flushing, the outlet gauge reading will be much lower and generally near zero. (See the bullet item below if the outlet gauge reading is below zero.) Observing inlet and outlet gauge readings as described above indicates that flushing is occurring. If the readings are not at approximately in line with the indicated values, then effective flushing is not occurring and the situation needs to be rectified so that effective flushing work can be performed. In all likelihood, pump repair or replacement is needed.

- Throttle (partially close) Valve No. 4 during direct flushing as necessary so that a vacuum does not develop on the return line to the air trap. A reading below zero on the outlet gauge would indicate the need for performing this throttling. Close monitoring of the outlet gauge for the piezometer during direct flushing is important. The small back pressure created by this throttling may also help air bubbles move along in the return line.

- During reverse flushing of a piezometer (water is being pumped into the outlet line and returning through the inlet line), the outlet gauge reading should exceed the corresponding AMRF column 1 value for the outlet gauge by approximately 30 feet, and the inlet gauge reading will be much lower, generally near zero, for the same reasons as discussed above. (See the next bullet item below if the inlet gauge reading is below zero.) Again, observing inlet and outlet gauge readings as described herein indicates that reverse flushing is occurring. If the readings are not approximately in line with the indicated values, then effective reverse flushing is not occurring and the situation needs to be rectified. Again, in all likelihood, pump repair or replacement is needed.

- Throttle (partially close) Valve No. 6 during reverse flushing as necessary so

that a vacuum does not develop on the return line to the air trap. A reading below zero on the inlet gauge would indicate the need for performing this throttling. Close monitoring of the inlet gauge for the piezometer during reverse flushing is important. The small back pressure created by this throttling may also help air bubbles move along in the return line.

- Some small air bubbles may not be removed during direct or reverse flushing, particularly if they are situated in nooks or crannies in the system where flushing of the system is most difficult. Sometimes closing and opening the outlet valve during direct flushing, and the inlet valve during reverse flushing, helps to remove an air bubble trapped within the return line during flushing.

- During all flushing work, visually monitor the air trap and record in column 4 of the AMFR any noteworthy observations, such as a significant quantity of air bubbles was noted, discolored water or debris was observed, an appreciable fall (or rise) in the fluid level occurred (note approximately how much the water level changed, should this occur), etc.

- The flushing time for each flushing operation (direct flush or reverse flush) should be as indicated on the AMRF. When flushing has been performed for at least the minimum time indicated, the flushing operation may be terminated when no bubbles or debris appear in the air trap for at least three minutes. The indicated flushing times are based on the distance of each piezometer from the terminal well. The "standard" flushing time is 5 to 15 minutes, and applies to piezometers within 500 feet of the terminal well. Greater flushing times are required for more distant instruments, as indicated on the AMRF. For instance, a piezometer 1,000 feet from the terminal well typically will require a flushing time of 20 to 30 minutes.

- If <u>substantial</u> amounts of fluid are being lost during a flushing operation, judgment can be used that flushing should be halted, and notes to that effect should be provided on the AMRF in column 4. However, it is important to note that for many piezometers (such as piezometers in a pervious zone of the dam embankment or foundation), loss of some fluid during flushing is normal.

- If there is no return flow, yet appropriate pressures on the piezometer line are being provided by the pump, then the piezometer line may be plugged. The attempt at flushing the line can be terminated after 5 minutes, and appropriate comments about what occurred should be recorded in column 4 of the AMRF.

- If water treated with QAC is introduced into piezometer lines that has not had QAC-treated water in it for awhile (say a year or more), the tubing may turn black as the QAC kills off a substantial population of bacteria that got out of control due to the lack of QAC in the previous months (and possibly years). This may appear alarming, but it is not a problem as the inert black matter will be cleared from the

tubing the next time flushing work is performed. QAC-treated water also may give off an odor (such as burning oil or rubber) when it has not been used in the system for a while. Care should be taken to avoid QAC-treated water from coming in contact with the electric pump when it is hot, as this could produce a very pungent odor in the well.

- Sometimes water cannot be circulated in hydraulic piezometer lines because insufficient pumping pressures are being developed. (Sometimes in these situations the tubing is reported to be plugged because the inadequacy of the pump is not recognized.) Inspection of the separate gauge readings recorded in AMRF columns 2 and 3 can quickly reveal why no water circulation occurred, due to insufficient pumping pressures, if pressures approximately 30 feet above the column 1 values were not achieved. If appropriate pressures can not be developed by the pump, then pump repair or replacement is indicated, unless the problem lies with the setting or operation of the bypass pressure relief valve. D-8460 should be consulted if the necessary pumping pressures can not be developed, yet the pump appears to be operating satisfactorily. D-8460 can also be consulted relative to pump repair or replacement needs.

With the above information in mind, the specific procedures to be used in flushing the piezometer lines are noted below:

i. Open, in sequence, Valve Nos. 2, 4, and 1. Then slowly open the inlet and outlet valves for one piezometer and flush the lines for this instrument. This is direct flushing. Record the approximate gauge readings of the inlet and outlet separate gauges in column 2 of the AMRF. Record observations during the direct flushing in column 4 of the AMRF. When direct flushing has been completed, close in sequence Valve Nos. 2 and 4, and record the actual flushing time on the "Inlet" line of AMRF column 5.

ii. Open, in sequence, Valve Nos. 5, and 6 and continue flushing. This is reverse flushing. Record the approximate gauge readings of the inlet and outlet separate gauges in column 3. Record observations during the reverse flushing in column 4 of the AMRF. When reverse flushing has been completed, close in sequence Valve Nos. 1, 6, and 5 and the inlet and outlet valves for the piezometer. Record the actual time reverse flushing was performed on the "Outlet" line of AMRF column 5.

iii. Repeat Steps i. and ii. for each piezometer in the terminal well, unless specific instructions exist to not flush particular instruments. Such instructions should be noted on the AMRF.

After this flushing work is completed, shut off the pump and close all valves in the terminal well, including the pump valves.

3. Master Gauge Reading Day

a. General

The Master Gauge Reading Day should be at least one week after the Flushing Work Day (to allow the piezometers to return toward equilibrium or near-equilibrium conditions after the flushing work), but not more than 1 month after Flushing Work Day (so that there is reasonable assurance that there is no air in any of the piezometer lines).

In general terms, the master gauge work consists conceptually of the following. Each separate gauge is addressed in turn. Fluid in the manifold line is pressurized to bring the reading at the master gauge to approximately the AMRF column 6 value for the separate gauge (within a couple feet). Then the valve to the separate gauge is opened to allow the same "pressurized water" to act simultaneously on the separate and master gauges. The separate and master gauge readings under these conditions are recorded in columns 7 and 8, respectively, on the AMRF, on the appropriate line. This information allows a check of the accuracy of each separate gauge, using the master gauge as the benchmark.

If the SOP for a dam includes site-specific instructions that differ from those presented in this section, follow the SOP instructions.

b. Check the AMRF column 10 values, if necessary

This step is only needed if separate gauge replacement work has occurred since the last time the AMRF form has been used. If this is the case, check the values already present in column 10 of the AMRF to ensure they are approximately correct. They represent the elevation of the separate gauge minus the elevation of the master gauge, rounded to the nearest ½ foot. A "+1.5" value means that the separate gauge is approximately 1.5 feet higher than the master gauge. The measuring point is to the center of the gauge. Any column 10 values that are not correct should be crossed out and the appropriate values should be indicated.

c. Initial separate gauge readings

Read the inlet and outlet separate gauges and record these readings in column 6 of the AMRF before starting the master gauge reading work. (These readings could be considered the "best" readings that will be obtained for the year, as the piezometer tubing has just recently been flushed.)

d. Flush the manifold lines and prepare to obtain master gauge readings

i. Check the entire system in the terminal well to ensure that all valves are closed. Close any valves that are not closed.

ii. Open the filler valve and the bleeder valve to the air trap. Fill the air trap with

fluid to within 3 inches of the top of the plastic air trap or to the top of the sight glass for a steel air trap. Then close the filler and bleeder valves.

iii. IMPORTANT NOTE: Add fluid to the air trap, to the levels noted in step ii. above, any time during the course of the flushing work that the fluid level in the air trap drops below one-half full.

iv. Flush the manifold lines in the terminal as described above in section IV.B.2.b.

v. With the inlet and outlet valves to the electric pump (or hand pump, if for some reason it is being used) open, follow the appropriate instructions in the following four subsections so that master gauge readings are obtained for all the separate gauges in the terminal well.

e. Obtaining master gauge reading data for an inlet separate gauge when the inlet separate gauge shows a positive reading

i. With the pump running, open in sequence Valve Nos. 1, 2, 6, and 7. Throttle Valve No. 1 and slowly close Valve Nos. 1 and 6 so as to set a pressure on the master gauge that is approximately the same as the Column 6 value on the AMRF for the separate gauge. Stop pumping when Valve Nos. 1 and 6 are fully closed.

ii. Open the inlet valve to the inlet separate gauge, let the separate gauge and master gauge stabilize on their readings (for the same pressurized water), and record the appropriate values in Columns 7 and 8 on the AMRF.

iii. Close the inlet valve to the inlet separate gauge.

iv. Open Valve No. 6 to relieve the water pressure in the manifold lines, and then close Valve No. 6.

v. Close Valve Nos. 2 and 7.

f. Obtaining master gauge reading data for an outlet separate gauge when the outlet separate gauge shows a positive reading

i. With the pump running, open in sequence Valve Nos. 1, 5, 4, and 7. Throttle Valve No. 1 and slowly close Valve Nos. 1 and 4 so as to set a pressure on the master gauge that is approximately the same as the Column 6 value on the AMRF for the separate gauge. Stop pumping when Valve Nos. 1 and 4 are fully closed.

ii. Open the outlet valve to the separate gauge, let the separate gauge and master gauge stabilize on their readings (for the same pressurized water), and record the appropriate values in Columns 7 and 8 on the AMRF.

iii. Close the outlet valve to the outlet separate gauge.

iv. Open Valve No. 4 to relieve the water pressure in the manifold lines, and then close Valve No. 4.

v. Close Valve Nos. 5 and 7.

g. Obtaining master gauge reading data for an inlet separate gauge when the inlet separate gauge shows a negative reading

i. Turn off the electric pump and close the inlet and outlet valves for the electric pump.

ii. Open the outlet valve on the hand pump and open Valve No. 1. (The inlet valve on the hand pump should remain closed.)

iii. Check to see if the handle on the hand pump is in the down position. If it is not, open Valve Nos. 5 and 4, push the handle to the down position, and then close Valve Nos. 5 and 4.

iv. Open Valve Nos. 2 and 7.

v. Apply a suction stroke on the hand pump by pulling up on the pump handle.

vi. Quickly close Valve No. 1, and then throttle and re-close Valve No. 1 so as to set a pressure on the master gauge that is approximately the same as the Column 6 value on the AMRF for the separate gauge.

vii. Open the inlet valve to the separate gauge, let the separate gauge and master gauge stabilize on their readings (for the same negative pressure), and record the appropriate values in Columns 7 and 8 on the AMRF.

viii. Close the inlet valve to the inlet separate gauge.

ix. Open Valve No. 6 to eliminate the negative water pressure in the manifold lines, and then close Valve No. 6.

x. Close Valve Nos. 2 and 7.

h. Obtaining master gauge reading data for an outlet separate gauge when the outlet separate gauge shows a negative reading

i. Turn off the electric pump and close the inlet and outlet valves for the electric pump.

ii. Open the outlet valve on the hand pump and open Valve No. 1. (The inlet valve on the hand pump should remain closed.)

iii. Check to see if the handle on the hand pump is in the down position. If it is not, open Valve Nos. 5 and 4, push the handle to the down position, and then close Valve Nos. 5 and 4.

iv. Open Valve Nos. 5 and 7.

v. Apply a suction stroke on the hand pump by pulling up on the pump handle.

vi. Quickly close Valve No. 1, and then throttle and re-close Valve No. 1 so as to set a pressure on the master gauge that is approximately the same as the Column 6 value on the AMRF for the separate gauge.

vii. Open the outlet valve to the separate gauge, let the separate gauge and master gauge stabilize on their readings (for the same negative pressure), and record the appropriate values in Columns 7 and 8 on the AMRF.

viii. Close the outlet valve to the outlet separate gauge.

ix. Open Valve No. 4 to eliminate the negative water pressure in the manifold lines, and then close Valve No. 4.

x. Close Valve Nos. 5 and 7.

i. At the conclusion of master gauge reading work

After all the master gauge reading work has been completed, be sure the electric pump is shut off and close all valves in the terminal well, including the pump valves.

4. Calculations

Columns 9 and 11 of the AMRF do not need to be completed before mailing the form to D-8460, but all other areas of the AMRF form do need to be filled in, including the heading information on each sheet, columns 1 through 8 of the main table of the form, and the comments area on the last sheet (if needed due to insufficient space available in AMRF column 4, or if space is needed for other notes or comments). For information purposes only, columns 9, 10, and 11, and the Master Gauge Correction Factor are discussed below:

a. Column 9 is simply a calculated entry, column 7 minus column 8, showing the difference between separate gauge and master gauge readings of the same "pressurized" water during the master gauge reading work. However, since the separate and master gauges are typically not installed at the same elevation, even separate and master gauges that are in perfect agreement will typically produce a non-zero value in column 9.

b. Column 10 is a "constant value" reflecting the elevation difference between the separate gauge and the master gauge (separate gauge elevation minus master gauge elevation), as noted above. If the separate gauge and master gauge readings recorded in columns 7 and 8, respectively, are in perfect agreement, then the value in column 9 will agree exactly with the value in column 10.

c. The Master Gauge Correction Factor is based on the idea that while the master gauge is a useful reference gauge, and generally would be expected to be highly accurate, it may not be exactly accurate (in an absolute sense) in all cases. In a simplified example, if there were 50 separate gauges and all the column 9 values were exactly 5 feet greater than the column 10 values, it would be more reasonable to conclude that the master gauge was reading 5 feet too low, rather than that all 50 separate gauges were reading too high by exactly the same amount (5 feet). This sort of logic is the basis for the Master Gauge Correction Factor. If the average of a number of different independent separate gauge readings is significantly different than the corresponding adjusted master gauge readings, then the error in the absolute pressure values more likely lies with the single master gauge reading than with all the separate gauge readings. The Master Gauge Correction Factor is used in calculating the column 11 values and is a positive number if the master gauge is reading too low. The Master Gauge Correction Factor is calculated as shown at the bottom of page 1 of the AMRF, using only the data from those separate gauges where apparently valid data is present in both columns 7 and 8. (Crossing out apparently invalid data on the AMRF makes it easy to see which rows of data should be excluded from this calculation.) The Master Gauge Correction Factor should be rounded to an accuracy no greater than 0.25 foot. If the Master Gauge Correction Factor is large, replacement of the master gauge may be appropriate.

d. Column 11 is the calculated adjustment factor to be applied to the raw separate gauge readings to bring each individual separate gauge reading to the most appropriate reading, based on the information available from the master gauge work. For each separate gauge, the column 11 value is calculated by taking the corresponding column 10 value, subtracting the corresponding column 9 value, and adding the Master Gauge Correction Factor.

C. Technical Comments

With the information now available from the AMRF, processing of hydraulic piezometer data and decisions about separate gauge replacement can proceed with more sophistication than the procedures previously used. Piezometer water pressures used in dam safety evaluation work should be based on adjusted separate gauge readings (based on the column 11 information), since this would represent the best estimate of the actual water pressure, using all the information available. In the same vein, the 5 foot and 10 foot agreement tests for determining apparent separate gauge data validity should be applied to <u>corrected</u> separate

gauge readings (column 6 plus column 11) rather than to the raw data (column 6).

A comparison of AMRF column 6 values with column 1 values provides a quick look at the impact of the flushing work (assuming no great change in the reservoir level between the flushing day and the master gauge day).

Appendix E
Example Separate Gauge Data Collection Form

7-1346 (3-89)
Bureau of Reclamation

PIEZOMETER READINGS
(Separate Gauges)

To: Technical Service Center
PO Box 25007, DFC
Denver CO 80225-0007
Attention: 8460

Modified _____ For
Dam SLY PARK DAM
Project Central Valley
Ref. Dwg. 540-D-57
Reservoir Water El. 3470.28

ENT'D

Date of Observation 1-31-99
Observer(s) KURT MIKKOLA
Sheet _____ of _____
Tailwater El. _____

Piez. No.	GAUGE READINGS			Tip* Constant	Average Press. at Tip	Piez. No.	GAUGE READINGS			Tip* Constant	Average Press. at Tip
	Inlet	Outlet	Average				Inlet	Outlet	Average		
1	73	121									
2	90	94									
3	93	90									
4	54	53									
5	20	21									
6	-3	-4									
—	—	—									
—	—	—									
9	134	135									
10	115	115									
11	94	93									
12	57	66									
13	24	40									
—	—	—									
15	82	59									
—	—	—									
17	75	77									

* The tip constant is the difference in elevation between a pair of gauges and the corresponding tip, measured to the nearest 0.5 foot. Use a plus (+) for tip constants when the tip is below the elevation of the gauges, and minus (-) when the tip is above the gauges. All readings in feet of water.

Appendix F
Example Blank Annual Maintenance Report Form (AMRF)

See the following three pages.

PLEASE MAIL OR FAX COMPLETED FORM TO D-8460

Mail to: USBR
P.O. Box 25007, Attn: D-8460
Denver, CO 80225-0007
Fax: (303) 445-6473

SAMPLE DAM

HYDRAULIC PIEZOMETERS – ANNUAL MAINTENANCE REPORT FORM

Flushing Work: Date: _____ Reservoir Elevation: _____ Performed by: _____

Master Gauge Readings: Date: _____ Reservoir Elevation: _____ Performed by: _____

		Flushing Work Day					Master Gauge Reading Day			Calculations *(may leave blank)*		
Hydraulic Piezometer Number (Recommended Flushing Time, in Minutes)		SG Reading Before Flushing (Col 1)	Approx. SG Reading During Direct Flushing (Col 2)	Approx. SG Reading During Reverse Flushing (Col 3)	Comments During Flushing (From Watching Air Trap) (Additional Space for comments is available on the last page) (Col 4)	Actual Flushing Time, in Minutes (Col 5)	SG Reading Before Starting Work (Col 6)	SG Reading (Col 7)	MG Reading (Col 8)	Diff. of Col 7 Minus Col 8 (Col 9)	Expected Diff. (Col 10)	Calculated SG Correction Amount (Col 11)
1 (15 - 25)	Inlet										-2.0	
	Outlet										-2.0	
2 (10 - 20)	Inlet										-2.0	
	Outlet										-2.0	
3 (5 - 15)	Inlet										-2.0	
	Outlet										-2.0	

Notes: SG = Separate Gauge; MG = Master Gauge; DF = Direct Flushing; RF = Reverse Flushing. "Master Gauge Reading Day" should be 1-4 weeks after "Flushing Work Day."

The indicated flushing time considers the distance from the piezometer to the terminal well. Flushing in one direction can be halted when no air bubbles or debris have been observed in the air trap for at least 3 minutes, as long as the minimum flushing time indicated has been met. Record actual flushing time (in minutes) in Col 5.

During direct flushing, Col 2 Inlet Reading should be approximately 30 feet higher than Col 1 Inlet Readings, and Col 2 Outlet Reading should be below Col 1 Outlet Reading and near zero.

During reverse flushing, Col 3 Outlet Reading should be approximately 30 feet higher than Col 1 Outlet Reading, and Col 3 Inlet Reading should be below Col 1 Inlet Reading and near zero.

Col 4 comments might be, for example: fluid level dropped 2 inches in 13 minutes, many air bubbles seen, debris seen, etc…

Col 6 is the "setting" pressure - manifold water is "pressurized" to bring the master gauge reading to match this reading (within a couple feet), then valves are closed to "lock in" the "pressurized water."

Col 7 and Col 8 readings are obtained at the same time, of the same "pressurized water" (after the valve to the piezometer is opened).

Col 10 "Expected Difference" is due to the slight elevation differential between the separate and master gauges.

Col 11 is computed as follows: Col 10 - Col 9 + Master Gauge Correction Factor, which is calculated as follows, considering only those gauges where apparently valid readings are present in both Col 7 and Col 8, and done separately for each master gauge if there is more than one terminal well at a dam:

Master Gauge Correction Factor *(To be calculated by D-8460):*

(Average of the Col 9 values) - (Average of the Col 10 values) = (_____) - (_____) = _____.

SAMPLE DAM **HYDRAULIC PIEZOMETERS – ANNUAL MAINTENANCE REPORT FORM** SHEET **2** OF **3**

Flushing Work: Date: _____ Reservoir Elevation: _____ Performed by: _____

Master Gauge Readings: Date: _____ Reservoir Elevation: _____ Performed by: _____

		Flushing Work Day					Master Gauge Reading Day			Calculations *(may leave blank)*		
Hydraulic Piezometer Number (Recommended Flushing Time, in Minutes)		SG Reading Before Flushing (Col 1)	Approx. SG Reading During Direct Flushing (Col 2)	Approx. SG Reading During Reverse Flushing (Col 3)	Comments During Flushing (From Watching Air Trap) (Additional Space for comments is available on the last page) (Col 4)	Actual Flushing Time, in Minutes (Col 5)	SG Reading Before Starting Work (Col 6)	SG Reading (Col 7)	MG Reading (Col 8)	Diff. of Col 7 Minus Col 8 (Col 9)	Expected Diff. (Col 10)	Calculated SG Correction Amount (Col 11)
4 (5 - 15)	Inlet										-2.0	
	Outlet										-2.0	
5 (5 - 15)	Inlet										-1.5	
	Outlet										-1.5	
6 (10 - 20)	Inlet										-1.5	
	Outlet										-1.5	
7 (5 - 15)	Inlet										-1.5	
	Outlet										-1.5	
8 (10 - 20)	Inlet										-1.5	
	Outlet										-1.5	
9 (5 - 15)	Inlet										-1.0	
	Outlet										-1.0	

SAMPLE DAM **HYDRAULIC PIEZOMETERS – ANNUAL MAINTENANCE REPORT FORM** SHEET **3** OF **3**

Flushing Date: _____ Performed By: _____ Master Gauge Work Date: _____ Performed By: _____

Any comments, information, etc. about unusual or noteworthy occurrences that took place during any portion of the hydraulic piezometer maintenance work:

Form modified: April 18, 2005

Appendix G
Example Completed Annual Maintenance Report Form (AMRF)

See the following three pages.

PLEASE MAIL OR FAX COMPLETED FORM TO D-8460

Mail to: USBR
P.O. Box 25007, Attn: D-8460
Denver, CO 80225-0007

Fax: (303) 445-6473

SAMPLE DAM

HYDRAULIC PIEZOMETERS – ANNUAL MAINTENANCE REPORT FORM

Flushing Work: Date: 1/20/05 Reservoir Elevation: 1641.40 Performed by: John Smith

Master Gauge Readings: Date: 2/2/05 Reservoir Elevation: 1640.78 Performed by: John Smith

		Flushing Work Day					Master Gauge Reading Day			Calculations *(may leave blank)*		
Hydraulic Piezometer Number (Recommended Flushing Time, in Minutes)		SG Reading Before Flushing (Col 1)	Approx. SG Reading During Direct Flushing (Col 2)	Approx. SG Reading During Reverse Flushing (Col 3)	Comments During Flushing (From Watching Air Trap) (Additional Space for comments is available on the last page) (Col 4)	Actual Flushing Time, in Minutes (Col 5)	SG Reading Before Starting Work (Col 6)	SG Reading (Col 7)	MG Reading (Col 8)	Diff. of Col 7 Minus Col 8 (Col 9)	Expected Diff. (Col 10)	Calculated SG Correction Amount (Col 11)
1 (15 - 25)	Inlet	14	44	0	No air present. Lost 0.1 foot water in direct flushing and 0.2 foot of water in reverse flushing.	15	14	12	14	-2	-2.0	+2.5
	Outlet	15	0	44		15	15	15	14	+1	-2.0	-0.5
2 (10 - 20)	Inlet	21	50	1	No air present. No water loss.	10	21	21	20	+1	-2.0	-0.5
	Outlet	22	3	50		10	22	22	20	+2	-2.0	-1.5
3 (5 - 15)	Inlet	9	40	0	No air present. Lost 0.13 foot water in direct flushing and 0.05 foot in reverse flushing.	5	9	8	7	+1	-2.0	-0.5
	Outlet	9	0	40		5	9	8	7	+1	-2.0	-0.5

Notes: SG = Separate Gauge; MG = Master Gauge; DF = Direct Flushing; RF = Reverse Flushing. "Master Gauge Reading Day" should be 1-4 weeks after "Flushing Work Day."

The indicated flushing time considers the distance from the piezometer to the terminal well. Flushing in one direction can be halted when no air bubbles or debris have been observed in the air trap for at least 3 minutes, as long as the minimum flushing time indicated has been met. Record actual flushing time (in minutes) in Col 5.

During direct flushing, Col 2 Inlet Reading should be approximately 30 feet higher than Col 1 Inlet Readings, and Col 2 Outlet Reading should be below Col 1 Outlet Reading and near zero.

During reverse flushing, Col 3 Outlet Reading should be approximately 30 feet higher than Col 1 Outlet Reading, and Col 3 Inlet Reading should be below Col 1 Inlet Reading and near zero.

Col 4 comments might be, for example: fluid level dropped 2 inches in 13 minutes, many air bubbles seen, debris seen, etc…

Col 6 is the "setting" pressure - manifold water is "pressurized" to bring the master gauge reading to match this reading (within a couple feet), then valves are closed to "lock in" the "pressurized water."

Col 7 and Col 8 readings are obtained at the same time, of the same "pressurized water" (after the valve to the piezometer is opened).

Col 10 "Expected Difference" is due to the slight elevation differential between the separate and master gauges.

Col 11 is computed as follows: Col 10 - Col 9 + Master Gauge Correction Factor, which is calculated as follows, considering only those gauges where apparently valid readings are present in both Col 7 and Col 8, and done separately for each master gauge if there is more than one terminal well at a dam:

Master Gauge Correction Factor *(To be calculated by D-8460):*

(Average of the Col 9 values) - (Average of the Col 10 values) = (+0.78) - (-1.67) = +2.44, say +2.5.

SAMPLE DAM **HYDRAULIC PIEZOMETERS – ANNUAL MAINTENANCE REPORT FORM** SHEET 2 OF 3

Flushing Work: Date: 1/20/05 Reservoir Elevation: 1641.40 Performed by: John Smith

Master Gauge Readings: Date: 2/2/05 Reservoir Elevation: 1640.78 Performed by: John Smith

		Flushing Work Day					Master Gauge Reading Day			Calculations *(may leave blank)*		
Hydraulic Piezometer Number (Recommended Flushing Time, in Minutes)		SG Reading Before Flushing (Col 1)	Approx. SG Reading During Direct Flushing (Col 2)	Approx. SG Reading During Reverse Flushing (Col 3)	Comments During Flushing (From Watching Air Trap) (Additional Space for comments is available on the last page) (Col 4)	Actual Flushing Time, in Minutes (Col 5)	SG Reading Before Starting Work (Col 6)	SG Reading (Col 7)	MG Reading (Col 8)	Diff. of Col 7 Minus Col 8 (Col 9)	Expected Diff. (Col 10)	Calculated SG Correction Amount (Col 11)
4 (5 - 15)	Inlet	5	35	0	Small air bubbles present. Lost 0.1 foot water in direct flushing and 0.05 foot water in reverse flushing.	5	4	4	4	0	-2.0	+0.5
	Outlet	6	0	35		5	5	5	4	+1	-2.0	-0.5
5 (5 - 15)	Inlet	0	30	0	Small air bubbles present. Lost 0.15 foot water in direct flushing and 0.2 foot water in reverse flushing.	5	0	0	0	0	-1.5	+1.0
	Outlet	1	0	30		5	0	0	0	0	-1.5	+1.0
6 (10 - 20)	Inlet	15	45	--	Pressure builds with no apparent flow. After the valve is closed the pressure drops very slowly. **Plugged?**	--	14	14	12	+2	-1.5	-1.0
	Outlet	15	--	45		--	14	14	12	+2	-1.5	-1.0
7 (5 - 15)	Inlet	-11	18	-1	No air present. Lost 0.73 foot water in direct flushing and lost 0.63 foot water in reverse flushing.	5	-12	-12	-13	+1	-1.5	0
	Outlet	-12	-1	18		5	-12	-12	-13	+1	-1.5	0
8 (10 - 20)	Inlet	14	45	0	Small air bubbles present. No water loss.	15	14	13	12	+1	-1.5	0
	Outlet	17	0	45	**Return water turbid in direct flush!**	15	13	13	12	+1	-1.5	0
9 (5 - 15)	Inlet	8	40	0	Small air bubbles present. No water loss.	5	8	8	8	0	-1.0	+1.5
	Outlet	9	0	40		5	10	10	9	+1	-1.0	+0.5

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Flushing Date: 1/20/05 Performed By: John Smith Master Gauge Work Date: 2/2/05 Performed By: John Smith

Any comments, information, etc. about unusual or noteworthy occurrences that took place during any portion of the hydraulic piezometer maintenance work:

All comments included in column 4 areas – nothing extra to add here.

Form modified: April 18, 2005