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1	1	Cog. Mgr. M. C. Hagood		19 May 94	H6-04	Steve Gorelick, Dept. of Geological & Environmental Sciences; Stanford University, Stanford, CA 94305-2225				3	
1	1	QA W.R. Thackaberry		5-24-94	H4-16						
1	1	Safety B.G. Baker		5/24/94	H4-67	S. J. Trent			H6-06	3	
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3		T. M. Brouns			K6-80	EPIC (1)			H6-08	3	
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K. J. Koegler Signature of EDT Originator — Date 13 May 94	Authorized Representative for Receiving Organization — Date	M. C. Hagood 17/94 Cognizant/Project Engineer's Manager — Date	[] Approved [] Approved w/comments [] Disapproved w/comments

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Purpose		ID Number (include revision, volume, etc.)
[] Speech or Presentation (Check only one suffix)	[] Reference	WHC-SD-EN-TP-043, Rev. 0
[] Full Paper	[X] Technical Report	
[] Summary	[] Thesis or Dissertation	List attachments.
[] Abstract	[] Manual	
[] Visual Aid	[] Brochure/Flier	
[] Speakers Bureau	[] Software/Database	Date Release Required
[] Poster Session	[] Controlled Document	April 24, 1994
[] Videotape	[] Other	

Title: Laboratory Test Plan In-Well Vapor Stripping System	Unclassified Category UC-	Impact Level QS

New or novel (patentable) subject matter? [X] No []Yes If "Yes", has disclosure been submitted by WHC or other company? [] No [] Yes Disclosure No(s).	Information received from others in confidence, such as proprietary data, trade secrets, and/or inventions? [X] No [] Yes (Identify)
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Date(s) of Conference or Meeting	City/State	Will proceedings be published?	[] Yes [] No
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Intended Audience
[] Internal [] Sponsor [X] External

Responsible Manager (Printed/Signature) Date
for M. C. Hagood 13 Apr 94

INFORMATION RELEASE ADMINISTRATION APPROVAL STAMP

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DS
Date 6-1-94

Date Cancelled	Date Disapproved

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Part 1

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6/1/94 M. Dolin

7. Abstract

WHC, 1994, *Laboratory Test Plan In-Well Vapor Strippping System*, WHC-SD-EN-TP-043, Rev. 0, prepared by T. J. Gilmore (PNL) and K. J. Koegler (WHC) for Westinghouse Hanford Company, Richland, Washington.

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9. Impact Level QS

10. RELEASE STAMP

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ACRONYMS

LEL	lower explosive limit
OSHA	Occupational Safety and Health Administration
PEL	permissible exposure limit
UEL	upper explosive limit
VOC	volatile organic carbon
WHC	Westinghouse Hanford Company

Metric Conversion Chart

The following conversion chart is provided to the reader as a tool to aid in conversion.

Into Metric Units

If You Know	Multiply By	To Get
Length		
inches	25.4	millimeters
inches	2.54	centimeters
feet	0.305	meters
yards	0.914	meters
miles	1.609	kilometers
Area		
sq. inches	6.452	sq. centimeters
sq. feet	0.093	sq. meters
sq. yards	.0836	sq. meters
sq. miles	2.6	sq. kilometers
acres	0.405	hectares
Mass (weight)		
ounces	28.35	grams
pounds	0.454	kilograms
short ton	0.907	metric ton
Volume		
teaspoons	5	milliliters
tablespoons	15	milliliters
fluid ounces	30	milliliters
cups	0.24	liters
pints	0.47	liters
quarts	0.95	liters
gallons	3.8	liters
cubic feet	0.028	cubic meters
cubic yards	0.765	cubic meters
Temperature		
Fahrenheit	subtract 32, then multiply by 5/9	Celsius

Out of Metric Units

If You Know	Multiply By	To Get
Length		
millimeters	0.039	inches
centimeters	0.394	inches
meters	3.281	feet
meters	1.094	yards
kilometers	0.621	miles
Area		
sq. centimeters	0.155	sq. inches
sq. meters	10.76	sq. feet
sq. meters	1.196	sq. yards
sq. kilometers	0.4	sq. miles
hectares	2.47	acres
Mass (weight)		
grams	0.035	ounces
kilograms	2.205	pounds
metric ton	1.102	short ton
Volume		
milliliters	0.033	fluid ounces
liters	2.1	pints
liters	1.057	quarts
liters	0.264	gallons
cubic meters	35.315	cubic feet
cubic meters	1.308	cubic yards
Temperature		
Celsius	multiply by 9/5, then add 32	Fahrenheit

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1. In-Well Vapor Stripping Test Apparatus 3

1.0 INTRODUCTION

This test plan describes the activities that will be conducted as a part of the laboratory testing of a full-scale mockup of the Stanford in-well vapor stripping system. These tests will be conducted to delineate design parameters for the in-well vapor stripping unit and to identify and quantify variables that are sensitive to the dynamic hydraulic effects induced by operation of the system. No radioactive materials are involved in this test.

In-well vapor stripping has been used successfully as an alternative to conventional pump-and-treat technology for remediation of volatile organic compound (VOC) contaminated groundwater in Europe and more recently in the United States. In-well vapor stripping permits in situ remediation of VOC-contaminated groundwater by combining an in-well vapor stripping system with a treatment well screened over two distinct intervals. The multiple-screened treatment well is used to extract and discharge groundwater simultaneously, resulting in the establishment of a vertical circulation groundwater flow cell in the aquifer. Groundwater extracted from the aquifer via the lower screened interval is treated for VOCs by in-well vapor stripping within the treatment well. This stripping causes aqueous phase VOCs to partition preferentially into a vapor phase. Treated groundwater is discharged back to the aquifer via the upper screened interval of the treatment well, while the vapor phase VOCs are simultaneously removed from the well bore and contained at the surface with a vacuum extraction system. Groundwater entrained into the vertical circulation flow cell becomes sequentially cleaned of VOC contamination in an efficient manner without the need for surface treatment and handling of contaminated groundwater. An added benefit of in-well vapor stripping is the ability to perform vadose zone vapor extraction concurrently with groundwater remediation. This uses the vacuum extraction capabilities of the in-well vapor stripping configured with the upper screened interval placed into the vadose zone above the water table.

An in-well vapor stripping system has been developed by faculty at Stanford University (Gvirtzman and Gorelick 1992) to treat VOC-contaminated groundwater. This system has been referred to as the Stanford in-well vapor stripping system. This system is currently in the conceptual design phase and has not been field tested. Large-scale laboratory testing of a prototype followed by field installation is planned.

2.0 TEST OBJECTIVES

The laboratory tests of the Stanford prototype and well mockup are designed to accomplish the following objectives.

- Calibrate the integral flow measurement weir and its associated transducer against a measured flow rate and develop relationships between the water flow measured by the weir system, air flow rate, and supply air pressure.

- Test the packer design for field installation.

- Test the effects of varying lift, head (submergence), and air flow rate on system performance.
- Test the effects of various diffusers on system performance.
- Gather data on the air holdup and actual air velocity within the vapor stripping well as a function of air flow rate and submergence.
- Evaluate the stripping efficiency of the in-well vapor stripping.

3.0 DESCRIPTION OF TEST ACTIVITIES

The test objectives outlined in Chapter 2.0 will be accomplished through a series of testing activities. These activities include the following:

- System checkout, instrument installation, and calibration
- Packer test
- Diffuser performance verification
- Varying lift and head test
- Tests under simulated aquifer conditions
- Stripping efficiency test.

These test activities are more fully described in Sections 3.1 through 3.6.

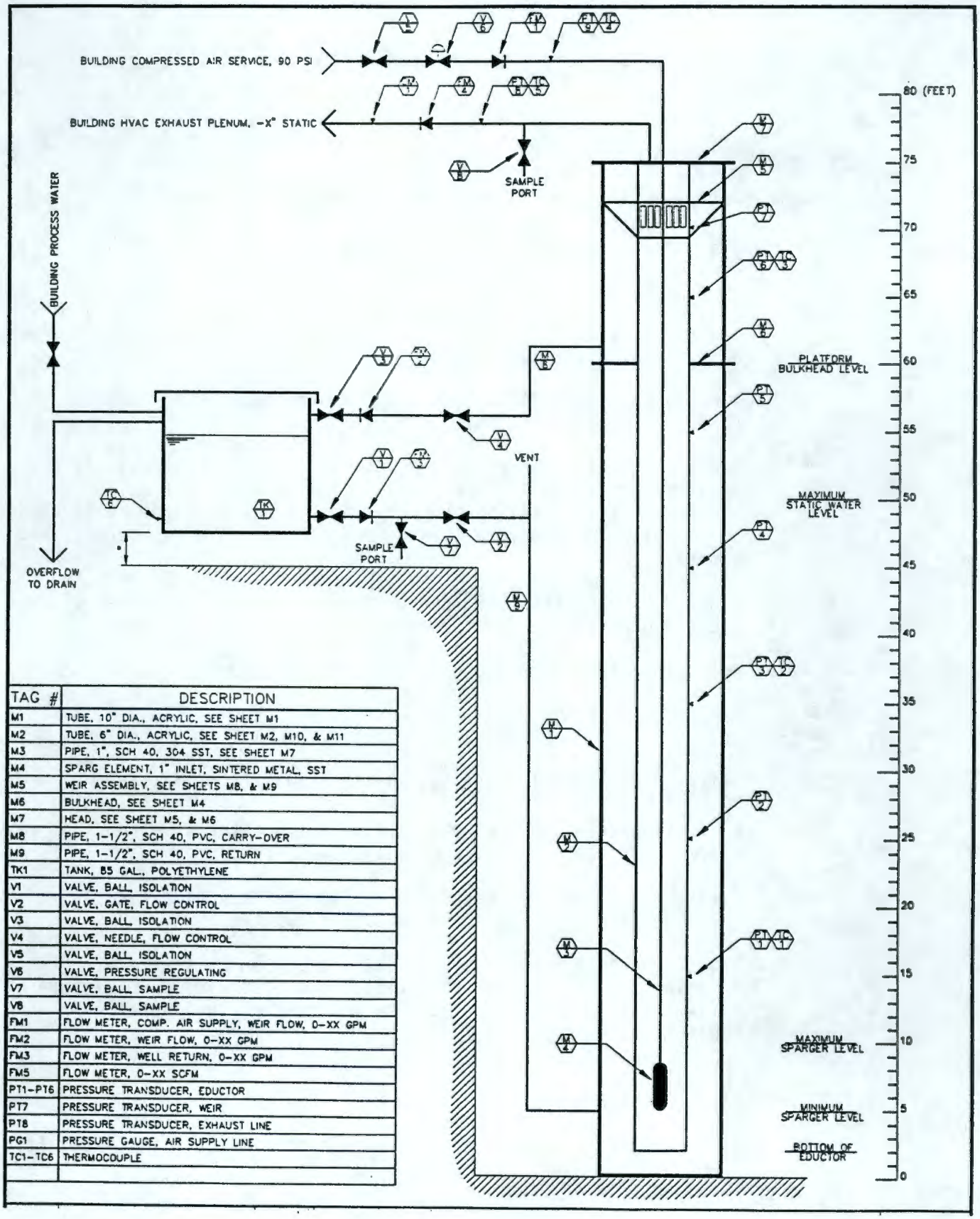
3.1 SYSTEM CHECKOUT, INSTRUMENT INSTALLATION, AND CALIBRATION

During this phase of testing, the system instrumentation will be calibrated and the system equipment will be checked for proper operation. Once the system is functioning properly, the weir and its associated pressure transducer will be calibrated against the water flow rate, which is measured by a calibrated inline flowmeter. A relationship between the water flow rate measured by the weir, the supply air flow rate, and the supply air pressure will be determined. Selected portions of the test activities will be videotaped using a portable camcorder and/or photographed using still cameras positioned at various heights along the well mockup.

3.1.1 Test Item

This activity will test the Stanford prototype weir device, sparger, and air eductor assemblies fabricated at the Hanford Site 306E Laboratory facility (Figure 1).

Figure 1. In-Well Vapor Stripping Test Apparatus.



TAG #	DESCRIPTION
M1	TUBE, 10" DIA., ACRYLIC, SEE SHEET M1
M2	TUBE, 6" DIA., ACRYLIC, SEE SHEET M2, M10, & M11
M3	PIPE, 1", SCH 40, 304 SST, SEE SHEET M7
M4	SPARG ELEMENT, 1" INLET, SINTERED METAL, SST
M5	WEIR ASSEMBLY, SEE SHEETS M8, & M9
M6	BULKHEAD, SEE SHEET M4
M7	HEAD, SEE SHEET M5, & M6
M8	PIPE, 1-1/2", SCH 40, PVC, CARRY-OVER
M9	PIPE, 1-1/2", SCH 40, PVC, RETURN
TK1	TANK, 85 GAL., POLYETHYLENE
V1	VALVE, BALL, ISOLATION
V2	VALVE, GATE, FLOW CONTROL
V3	VALVE, BALL, ISOLATION
V4	VALVE, NEEDLE, FLOW CONTROL
V5	VALVE, BALL, ISOLATION
V6	VALVE, PRESSURE REGULATING
V7	VALVE, BALL, SAMPLE
V8	VALVE, BALL, SAMPLE
FM1	FLOW METER, COMP. AIR SUPPLY, WEIR FLOW, 0-XX GPM
FM2	FLOW METER, WEIR FLOW, 0-XX GPM
FM3	FLOW METER, WELL RETURN, 0-XX GPM
FM5	FLOW METER, 0-XX SCFM
PT1-PT6	PRESSURE TRANSDUCER, EDUCTOR
PT7	PRESSURE TRANSDUCER, WEIR
PT8	PRESSURE TRANSDUCER, EXHAUST LINE
PG1	PRESSURE GAUGE, AIR SUPPLY LINE
TC1-TC6	THERMOCOUPLE

3.1.2 Test Environment

This activity will occur in the 306E Laboratory facility in the 300 Area. The full-scale Stanford prototype and well mockup will be installed in the test pit of the 306E Laboratory.

3.1.3 Equipment and Facilities

This testing activity will require the following equipment:

- The circulation well mockup assembly installed in the 306E Laboratory test pit (see Figure 1)
- An air compressor or building compressed air supply capable of providing between 1 and 25 ft^3/min of air flow at a pressure of up to 95 ft of water (approximately 40 lb/in^2)
- A building ventilation/vessel vent system capable of removing up to 25 ft^3/min of air flow
- Supporting instrumentation, including air flow, temperature, and pressure meters on the air supply and discharge; a liquid flowmeter factory calibrated to $\pm$ 1% accuracy over the range of 10 to 100 gal/min; pressure transducers; combustible gas meters; and a datalogger
- 5-gal U.S. Department of Transportation approved container of liquified petroleum gas (propane)
- Approximately 200 to 250 gal of sanitary water.

3.1.4 Data

Data collected during this activity will include the following:

- Water flow rate measured by the liquid flowmeter as a function of system air flow rate and supply air pressure
- Pressure measured by the transducer in the weir as a function of the flow rate measured by the liquid flowmeter
- Pressure and temperature (both wet and dry bulb) of the air stream entering and exiting the test well and of the air/water mixture at various points within the well as measured by the installed monitoring equipment.

3.1.5 Criteria/Constraints

No special criteria or constraints are applicable to this test activity.

3.2 PACKER TEST

During this testing activity, the proposed well packer design for the Stanford system will be leak tested. After leak testing, several inches of silty sand will be placed on the packer to simulate the buildup of sediments during operation, and the effect on the packer seal and withdrawal of the packer assembly will be determined.

3.2.1 Test Item

The item to be tested during this activity is the prototype integral in-well packer assembly to be manufactured as a part of the field Stanford system.

3.2.2 Test Environment

This activity will occur in the 306E Laboratory using a test bed consisting of an 11- to 12-ft-long by 6-in.-diameter stainless steel pipe inside an 11- to 12-ft-long by 10-in.-diameter stainless steel pipe. The packer will be placed between the 6-in. and 10-in. pipes.

3.2.3 Equipment and Facilities

This activity will require the test bed described above, a small amount of sand (less than 25 lb), and approximately 35 gal of sanitary water.

3.2.4 Data

During this test, the test bed and packer will be visually observed to determine if leakage is occurring. The ease of withdrawing the packer with a sediment buildup will be subjectively determined.

3.2.5 Criteria/Constraints

No special criteria or constraints are applicable to this test activity.

3.3 DIFFUSER PERFORMANCE VERIFICATION

During this test activity, each diffuser will be tested to determine the range of liquid flow rates that can be achieved at a constant lift of 25 to 27 ft. The bubble size and production rate of each diffuser will be observed and qualitatively evaluated. Selected portions of the test activities will be videotaped using a portable camcorder and/or photographed using still cameras positioned at various heights along the well mockup.

3.3.1 Test Item

This activity will test the Stanford prototype eductor pipe and diffuser assembly fabricated at the 306E Laboratory facility. The eductor pipe will be fitted with a variety of sintered metal diffuser devices of varying porosities.

3.3.2 Test Environment

This activity will occur in the 306E Laboratory facility in the 300 Area. The full-scale Stanford prototype and well mockup will be installed in the test pit of the 306E Laboratory.

3.3.3 Equipment and Facilities

Equipment and facilities required for this activity are the same as those described in Section 3.1.3.

3.3.4 Data

The following data will be collected during this activity:

- Supply air pressure, air temperature, and water temperature as a function of air flow rate
- Water flow rate (measured both by the weir/transducer and the water flowmeter) as a function of air flow rate and water head at a constant lift
- Bubble size and production rate based upon qualitative observations of the well mockup and scaled photographs
- Pressure and temperature (both wet and dry bulb) of the air stream entering and exiting the test well and of the air/water mixture at various points within the well as measured by the installed monitoring equipment.

3.3.5 Criteria/Constraints

No special criteria or constraints are applicable to this test activity.

3.4 VARYING LIFT AND HEAD TESTS

Of the diffuser assemblies that pass the minimum performance tests described in Section 3.3, the two assemblies that are anticipated to exhibit the highest mass transfer rates (based upon bubble size and production rate evaluations) will be tested further. These tests will evaluate system operation, including well drawdown/mounding, at various combinations of lift and head (submergence). Selected portions of the test activities will be

videotaped using a portable camcorder and/or photographed using still cameras positioned at various heights along the well mockup.

3.4.1 Test Item

The test item for this activity is the Stanford assembly described in Section 3.1.1, fitted with the diffusers described in Section 3.4.

3.4.2 Test Environment

This activity will occur in the 306E Laboratory facility in the 300 Area. The full-scale Stanford prototype and well mockup will be installed in the test pit of the 306E Laboratory.

3.4.3 Equipment and Facilities

Equipment and facilities required for this activity are the same as those described in Section 3.1.3.

3.4.4 Data

Data to be collected during this activity will include the following:

- Supply air pressure, air temperature, and water temperature as a function of air flow rate
- Water flow rate (measured both by the weir/transducer and the water flowmeter) as a function of air flow rate and water head at a constant lift
- Bubble size and production rate, based upon qualitative observations of the well mockup and scaled photographs
- Pressure and temperature (both wet and dry bulb) of the air stream entering and exiting the test well and of the air/water mixture at various points within the well as measured by the installed monitoring equipment.

3.4.5 Criteria/Constraints

No special criteria or constraints are applicable to this test activity.

3.5 TESTS UNDER SIMULATED AQUIFER CONDITIONS

These tests will use valving to introduce flow resistance in the piping between the test well mockup and the surge tank. The flow resistances will cause water level drawdown/mounding in the test well, simulating the

conditions that will occur during actual field operation of the Stanford system.

3.5.1 Test Item

The test item for this activity is the Stanford assembly described in Section 3.1.1, fitted with the diffusers described in Section 3.4.

3.5.2 Test Environment

This activity will occur in the 306E Laboratory facility in the 300 Area. The full-scale Stanford prototype and well mockup will be installed in the test pit of the 306E Laboratory.

3.5.3 Equipment and Facilities

Equipment and facilities required for this activity are the same as those described in Section 3.1.3.

3.5.4 Data

The following data will be collected during this activity:

- Supply air pressure, air temperature, and water temperature as a function of air flow rate
- Water flow rate (measured both by the weir/transducer and the water flowmeter) as a function of air flow rate and water head at a constant lift
- Bubble size and production rate, based upon qualitative observations of the well mockup and scaled photographs
- Pressure and temperature (both wet and dry bulb) of the air stream entering and exiting the test well and of the air/water mixture at various points within the well as measured by the installed monitoring equipment.
- Static and operating water levels in the upper and lower sections of the outer 10-in. well.

3.5.5 Criteria/Constraints

No special criteria or constraints are applicable to this test activity.

3.6 STRIPPING EFFICIENCY TESTS

Propane has been initially selected for use in the stripping efficiency test. Alternate compounds may also be considered. The air stripping efficiency of the vapor stripping well will be evaluated by mixing propane gas into the recirculated liquid and comparing the propane concentration in the liquid entering the stripping well to the propane concentrations in the liquid at the top of the well and in the gas stream exiting the well. Propane gas has been selected because it has a Henry's Law constant similar to that of carbon tetrachloride but does not present the health and environmental concerns of carbon tetrachloride.

3.6.1 Test Item

The test item for this activity is the Stanford assembly described in Section 3.1.1, fitted with the diffusers described in Section 3.4.

3.6.2 Test Environment

This activity will occur in the 306E Laboratory facility in the 300 Area. The full-scale Stanford prototype and well mockup will be installed in the test pit of the 306E Laboratory.

3.6.3 Equipment and Facilities

Equipment and facilities required for this activity are the same as those described in Section 3.1.3. Additionally, less than 5 gal of propane gas will be used during the course of the test.

3.6.4 Data

Data to be collected during this activity will include the following:

- Supply air pressure, air temperature, and water temperature as a function of air flow rate
- Water flow rate (measured both by the weir/transducer and the water flowmeter) as a function of air flow rate and water head at a constant lift
- Bubble size and production rate, based upon qualitative observations of the well mockup and scaled photographs
- Pressure and temperature (both wet and dry bulb) of the air stream entering and exiting the test well and of the air/water mixture at various points within the well as measured by the installed monitoring equipment
- Propane concentrations in the water entering and exiting the test well and in the gas stream entering and exiting the test well.

3.6.5 Criteria/Constraints

Special criteria and constraints applicable to this test activity are discussed under Safety in Chapter 6.0.

4.0 EXPECTED RESULTS

4.1 SYSTEM CHECKOUT, INSTRUMENT INSTALLATION, AND CALIBRATION

Relationships between pressures measured in the Stanford flow weir and actual liquid flow rates will be determined. To be successful, the weir and transducer must allow the actual flow rate to be determined independent of the supply air flow rate used.

During the calibration of the weir assembly, the overall ability of the system to provide 20 ft of lift at a head of 40 ft will be checked to ensure that the system design can reasonably accomplish the objectives stated for other test activities.

Fluid pressure and temperature at various heights within the test well will be continuously monitored and logged. These data will be used to estimate the gas holdup of the vapor stripping well under various operating conditions. Pressure transducers should be able to detect at least a 0.5 psi change. Thermocouples should be able to detect at least a 0.5 °C change, and flowmeters should be able to detect at least a 0.5 gal/min change.

4.2 PACKER TEST

To be considered successful, the prototype packer assembly should allow no visible leakage of water from the region above the packer to the region below the packer both before and after the simulated sediment is added to the system under maximum expected mounding conditions. The packer should also be able to be withdrawn from the test bed freely, with no jamming, when removal is attempted after sediments are added.

4.3 DIFFUSER PERFORMANCE VERIFICATION

Diffusers that pass the performance verification test will be able to sustain 20 ft of lift and 40 ft of head (submergence) at operating flow rates of between 10 and 40 gal/min with no evidence of annular air flow. Diffusers selected for further evaluation will achieve the widest range of liquid flow rates and will produce the highest volumes of small air bubbles without producing annular air flow.

4.4 VARYING LIFT AND HEAD TEST

This test activity will be considered successful if at least one diffuser assembly is able to sustain a minimum of 10 gal/min of water flow over a variety of lift and head combinations without producing annular flow. Transient drawdown/mounding combinations will also be observed.

4.5 TESTS UNDER SIMULATED AQUIFER CONDITIONS

These tests will evaluate the operable range of flow rates, lifts, and submergences of a test well with design characteristics similar to the test well mockup. Conditions that would adversely affect the performance of the well in the field (e.g., excessive drawdown or water mounding that would interfere with the flow measurement weir) will be identified.

4.6 STRIPPING EFFICIENCY TEST

The propane in the gas leaving the vapor stripping well is anticipated to be nearly at equilibrium with the propane in the liquid within the well for the bubble and small slug flow regimes. The purpose of the stripping test is to confirm and refine the correlations and equations used to predict the vapor phase VOC concentrations achieved by the in-well vapor stripping.

5.0 TEST PROCEDURE

The following sections provide step-by-step instructions for performing the test activities described in Chapter 3.0.

5.1 SYSTEM CHECKOUT, INSTRUMENT INSTALLATION, AND CALIBRATION

5.1.1 Initial Conditions

The following conditions must exist before test activities are initiated.

- The Stanford prototype system will have been installed in the well mockup.
- A diffuser will have been installed on the Stanford eductor.
- The main well will have been filled with water to the static water level.

- The water level in the surge tank will be in equilibrium with the water level in the main well.
- All system valves will be closed.

5.1.2 Verify Instrument Calibrations

5.1.2.1 Supply Air Instrumentation. Ensure that supply air flowmeter, temperature gauge, and pressure gauge calibrations have been performed in accordance with manufacturer's instructions and/or WHC procedures and that calibrations are current. Calibrate instruments if required. Record calibration date on data sheet.

5.1.2.2 Liquid Flowmeter. Verify that liquid flowmeter has been calibrated by manufacturer before receipt.

5.1.2.3 Pressure Transducers. Ensure that the pressure transducers have been calibrated in accordance with manufacturer's instructions and/or WHC procedures and that calibrations are current. Calibrate if required. Record calibration date on data sheet.

5.1.2.4 Datalogger. Ensure that the datalogger used to record signals from the pressure transducers and thermocouples has been calibrated in accordance with manufacturer's instructions and/or WHC procedures and that calibrations are current. Calibrate if required. Record calibration date on data sheet.

5.1.3 Establish Initial Flows

5.1.3.1 Align System Valving Properly. Open the return valves fully between test well to reservoir tank and between the reservoir tank and the test well. Ensure that sample valves are in the flow-through (and not sampling) positions. Ensure that the sewer discharge valve is in the recirculation position.

5.1.3.2 Begin Air Flow. Open air supply valve and adjust to allow approximately 0.25 $stdft^3$/min air flow.

5.1.4 Calibrate Pressure Weir

5.1.4.1 Establish Initial Flow Condition. Allow liquid flowmeter readings and weir pressure transducers to attain steady state at 0.25 $stdft^3$/min air flow. Record following system variables when steady state is attained:

- Time steady state conditions were observed
- Supply and exhaust air flow rate
- Supply and exhaust air wet and dry bulb temperatures
- Liquid flow rate, as measured by reservoir tank flowmeter
- Fluid pressures and temperatures along test well height
- Observed flow regime (bubble, slug, churn, annular)
- Weir transducer pressure reading.

5.1.4.2 Calibrate Overflow Range. Repeat Step 5.1.4.1, increasing air flow rate in 0.25 stdft^3/min increments until annular flow is observed or maximum supply air flow is attained. Record the system variables listed in Step 5.1.4.1 for each air flow setting.

5.2 DIFFUSER LIFT VERIFICATION

5.2.1 Initial Conditions

Repeat system verification steps listed in Sections 5.1.1 and 5.1.2.

5.2.2 Establish Initial Flows

5.2.2.1 Align System Valving Properly. Open the return valves fully between test well to reservoir tank and between the reservoir tank and the test well. Ensure that sample valves are in the flow-through (and not sampling) positions. Ensure that the sewer discharge valve is in the recirculation position.

5.2.2.2 Begin Air Flow. Open air supply valve and adjust to allow approximately 0.25 stdft^3/min air flow.

5.2.3 Verify Diffuser Performance

5.2.3.1 Verify Performance at Minimum Flow. Adjust air flow to establish 10 gal/min liquid flow as measured by liquid flowmeter (approximately 0.25 stdft^3/min air flow). Allow system to stabilize, and record following variables:

- Time steady state conditions were observed
- Supply and exhaust air flow rate
- Supply and exhaust air wet and dry bulb temperatures
- Liquid flow rate, as measured by reservoir tank flowmeter
- Fluid pressures and temperatures along test well height
- Observed flow regime (bubble, slug, churn, annular)
- Weir transducer pressure reading.

5.2.3.2 Verify Performance at Increasing Flow Rates. Increase air flow in 0.25 stdft^3/min increments until maximum air flow rate achievable by the supply system is reached or annular flow is observed. At each air flow rate, record the system variables listed in Section 5.3.3.1.

5.2.4 Change Diffuser Assembly

NOTE: Repeat the steps in Section 5.3.4 for each diffuser assembly to be tested.

5.2.4.1 Withdraw Stanford System. Remove Stanford system from well mockup.

5.2.4.2 Install New Diffuser Assembly. Disassemble Stanford system as

required to expose sparger and diffuser. Remove current diffuser from Stanford system. Install new diffuser assembly.

5.2.4.3 Reinsert Stanford System and Test New Diffuser Assembly. Reinsert Stanford system into well mockup. Perform Steps in Sections 5.3.1 through 5.3.3.2.

5.3 VARYING LIFT AND HEAD TESTS

5.3.1 Initial Conditions

Repeat system verification steps listed in Sections 5.1.1 and 5.1.2.

5.3.2 Establish Initial Flows

5.3.2.1 Align System Valving Properly. Open the return valves fully between test well to reservoir tank and between the reservoir tank and the test well. Ensure that sample valves are in the flow-through (and not sampling) positions. Ensure that the sewer discharge valve is in the recirculation position.

5.3.2.2 Begin Air Flow. Open air supply valve and adjust to allow approximately 0.25 stdft^3/min air flow.

5.3.3 Verify Diffuser Performance at Nominal Operating Conditions

NOTE: For Steps in Sections 5.4.3.1 and 5.4.3.2, the water level in the test well and surge tank should be at the maximum static water level.

5.3.3.1 Verify Performance at Minimum Flow. Adjust air flow to establish 10 gal/min liquid flow as measured by liquid flowmeter (approximately 0.25-stdft^3/min air flow). Allow system to stabilize and record following variables:

- Time steady state conditions were observed
- Supply and exhaust air flow rate
- Supply and exhaust air wet and dry bulb temperatures
- Liquid flow rate, as measured by reservoir tank flowmeter
- Fluid pressures and temperatures along test well height
- Observed flow regime (bubble, slug, churn, annular)
- Water level in upper and lower sections of the 10-in. outer well.
- Weir transducer pressure reading.

5.3.3.2 Verify Performance at Maximum Flow Rate. Increase the air flow rate to the value corresponding to the maximum flow rate achieved for that diffuser in the tests in Section 5.3. Once steady state conditions are achieved, record the variables noted in Section 5.4.3.1.

5.3.4 Observe Performance at Decreased Head/Increased Lift

NOTE: Every 1 ft of distance along the test well equals approximately 3.5 gal of water.

5.3.4.1 Decrease Operating Head/Increase Lift. While system is running, switch the recirculation/sewer discharge valve to the sewer discharge position. Allow 8 to 9 gal of water to flow to the sewer. Reset valve to the recirculate position. This should reduce the static water level in the test well by between 2.25 and 2.5 ft.

5.3.4.2 Verify Performance Overflow Rate Range. Adjust air flow until 10 gal/min liquid flow rate is achieved as measured by the liquid flowmeter. Allow system to stabilize and record system variables noted in Section 5.4.3.1. Increase air flow in 0.25 stdft^3/min increments until maximum air flow rate achievable by the supply system is reached or annular flow is observed. At each air flow rate, record the system variables noted in Section 5.4.3.1 once steady state conditions are achieved. Shut down air flows, allow system fluid levels to equilibrate, and record actual static water level in the test well.

5.3.4.3 Observe Performance at Decreased Head/Increased Lift. Restart well flows as described in Sections 5.4.3.1 and 5.4.3.2. Further reduce head/increase lift as described in Section 5.4.4.1. Observe system performance over flow rate range as described in Section 5.4.4.2. Repeat until one of the following conditions is reached:

- 10 gal/min water flow cannot be sustained with the maximum air flow available
- 10 gal/min water flow cannot be sustained without encountering annular flow conditions.

5.3.5 Change Diffuser Assembly

NOTE: Repeat the steps in Section 5.4.5 for each diffuser assembly to be tested.

5.3.5.1 Withdraw Stanford System. Remove Stanford system from well mockup.

5.3.5.2 Install New Diffuser Assembly. Disassemble Stanford system as required to expose sparger and diffuser. Remove current diffuser from Stanford system. Install new diffuser assembly.

5.3.5.3 Reinsert Stanford System. Reinsert Stanford system into well mockup. Perform Steps in Sections 5.4.1 through 5.4.2.2.

5.4 TESTS UNDER SIMULATED AQUIFER CONDITIONS

5.4.1 Initial Conditions

Repeat system verification steps listed in Sections 5.1.1 and 5.1.2.

5.4.2 Establish Initial Flows

Establish initial system flows as described in Section 5.1.3.

5.4.3 Adjust Resistance to Flow

NOTE: At a 20-gal/min flow rate and a 30-ft/day effective flow resistance (aquifer conductivity plus well losses) and a 10-ft well screen section, a drawdown of approximately 6 ft is anticipated to occur in an actual well installation with geometry similar to that of the test well.

This section may be repeated using different initial drawdown settings to simulate various effective flow resistances.

5.4.3.1 Increase System Flow Rate to 20 gal/min. Adjust air flow rate as required to achieve a 20-gal/min recirculating flow rate. Allow system fluid levels to equilibrate.

5.4.3.2 Adjust Return Flow From Test Well. Using upper control (gate or needle) valve, reduce the return flow from the test well until the level in the upper portion of the 10-in. test well increases to approximately 6 ft above the separation plate. Adjust the flow as required using the lower control valve to maintain 6-ft increase in level.

5.4.3.3 Adjust Return Flow from Test Well. Using lower control (gate or needle) valve, reduce the return flow to the test well until the level in the lower portion of the 10-in. test well decreases approximately 6 ft below the maximum static water level (to about 44 ft).

5.4.4 Diffuser Lift Verification

Repeat tests described in Section 5.3. Do not adjust control valves during tests.

5.4.5 Varying Lift and Head Tests

Repeat tests described in Section 5.4. Do not adjust control valves during tests.

5.5 AIR STRIPPING EFFECTIVENESS TEST

The following instructions will test the air stripping effectiveness of

the Stanford system on the test well under the following conditions:

- 10 gal/min liquid flow rate
- Simulated 2.5 mg/L, or 1.6×10^{-6} mol/L, carbon tetrachloride concentration in groundwater
- Valving set to simulate an effective flow resistance of 30 ft/day.

5.5.1 Initial Conditions

Repeat Steps in Sections 5.5.1 through 5.5.3.3. In addition, perform the following steps:

- Ensure that all propane piping and valves have been leak tested at normal operating pressure
- Ensure that combustible gas meter has been calibrated to propane
- Confirm that ventilation system, including surge tank ventilation system, is operational
- Adjust airflow to obtain a 10 gal/min liquid flow rate.

5.5.2 Initiate Once-Through Liquid Flow.

5.5.2.1 Open Water Supply Valve. Open water supply valve and establish a 10 gal/min flow of water to the test system.

5.5.3 Perform Stripping Efficiency Test

NOTE: The anticipated carbon tetrachloride concentration in groundwater at the 200 West Area in-well vapor stripping test site is approximately 2.5 mg/L, or 1.6×10^{-6} mol/L. To obtain a 1.6×10^{-6} mol/L concentration of propane in the water, approximately 0.001 L of pure propane must be dissolved into every gallon of water at standard conditions (1 atm pressure and 0 °C). The following instructions assume that approximately 90% of the pure propane injected into a 10 gal/min water supply is dissolved; the flow settings may be adjusted to obtain differing concentrations for various water supply flow rates.

5.5.3.1 Initiate Propane Flows. Open propane supply valve and adjust valving until a 0.7 L/hr propane flow rate is established.

NOTE: No smoking or open flames are allowed in the vicinity of the propane storage area or test well mockup. Propane flows must be shut off if any of the following conditions occur:

- Building or test well mockup system ventilation is interrupted
- Propane piping must be repaired or adjusted (fittings tightened)

- Water flow is interrupted
- Test activities are delayed or test system is unattended.

The airspace within the surge tank will be monitored every 15 minutes while the propane is flowing. If propane concentrations in the surge tank exceed 15% of the lower explosive limit (LEL), propane flows will be shut off and not reestablished until propane concentrations in the surge tank fall to background levels. For propane, 15% of the LEL is equivalent to an air concentration of 3,200 ppm.

5.5.3.2 Record System Data. Monitor the exhaust system combustible gas meter. The combustible gas meter should be able to detect propane to at least 10 ppm-v. When the combustible gas meter reading stabilizes (anticipated readings are on the order of 100 to 1,000 ppmv), record system data:

- Time steady state conditions were observed
- Supply and exhaust air flow rate
- Supply and exhaust air wet and dry bulb temperatures
- Liquid flow rate, as measured by reservoir tank flowmeter
- Fluid pressures and temperatures along test well height
- Observed flow regime (bubble, slug, churn, annular)
- Water level in upper and lower sections of the 10 in. outer well.
- Weir transducer pressure reading.

5.5.3.3 Collect Air and Water Samples. Collect air and water samples at the following locations:

- Inlet air sample valve
- Outlet air sample valve
- Water return to test well sample valve
- Water return from test well sample valve.

Air samples are to be collected in Tedlar (a registered trademark of E.I. du Pont de Nemours and Company, Wilmington, Delaware) bags. Water samples are to be collected in 40 mL glass vials with nonstick caps and septa. Take care to minimize agitation of the water samples, and ensure that no airspace is left in the sample vials. Submit samples for analysis for propane by gas chromatography. Analysis should be able to detect at least 20 ppb propane in water and air.

5.5.3.4 Test Conclusion. Once all readings are obtained and samples collected, close propane supply valve. Set sewer discharge/recirculation flow valve to the recirculation position. Close water supply valve.

6.0 SAFETY

The key safety concerns for this test include the following:

- Entry into the 306E Laboratory pit
- Potential hazards caused by propane.

6.1 ENTRY INTO THE 306E LABORATORY PIT

Entry into the 306E Laboratory pit will be required for several test activities, including installation and operation of test equipment. Entries into the 306E Laboratory pit will be performed in accordance with standard approved procedures.

6.2 PROPANE HAZARDS

Propane has been chosen for use in these tests as a low-toxicity, noncarcinogenic surrogate for carbon tetrachloride. Other compounds may be considered for use in these stripping tests. On a molar basis, the Henry's Law constant for propane (2.2×10^{-2} atm-mol/m^3) is approximately the same as that for carbon tetrachloride (2.41×10^{-2} to 3.0×10^{-2} atm-mol/m^3); therefore, propane is an appropriate substitute for carbon tetrachloride for test purposes. Propane was selected for these tests using a process that considered the following:

- The Henry's Law constants and solubilities of potential surrogate compounds
- Environmental and health and safety considerations, including whether or not the disposal of wastes or air emissions generated by test activities would be subject to state and federal environmental regulations)
- Availability, cost, and ease of use.

6.2.1 Propane Properties

Propane is a colorless, heavier-than-air gas that is flammable and can act on the central nervous system. Commercial propane typically has an odorant added to allow detection by smell and is generally supplied as a liquified compressed gas. Inhalation can cause dizziness or disorientation. Skin contact can cause excitation or frostbite because of the low temperatures caused by the expansion of the pressurized liquid into the gas phase. Clothing that becomes saturated with propane can be flammable. The LEL for propane is 2.1 vol%; the upper explosive limit (UEL) is 9.5 vol%. The Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for propane is 1,000 ppm (1,800 mg/m^3).

6.2.2 Safety Features and Administrative Controls

A separate safety review will be performed at the 306E Laboratory before initiating the stripping efficiency tests. Propane flow rates will be controlled such that the propane concentrations in the offgas from the test well, as measured by the inline combustible gas meter, remain less than 1,000 ppm. This maximum concentration is approximately 5% of the LEL. Therefore, it is unlikely that the offgas from the test well poses a fire or explosion hazard. Similarly, concentrations of propane in the test well offgas will be at or below the PEL.

Excess propane that does not dissolve in the supply water will be de-entrained in the surge tank. At a 40 gal/min water flow rate (maximum anticipated), up to 0.27 L/hr (0.07 gal/hr, or 0.001 gal/min) of propane could potentially accumulate in the surge tank, assuming that propane is injected at the rate required to obtain a 1.6×10^{-6} mol/L concentration in the water with a 90% dissolution. The surge tank will be connected to the building exhaust system to remove any excess propane from the airspace within the tank. The airspace within the surge tank will be periodically monitored using a portable combustible gas meter to ensure that propane concentrations in the tank remain below 15% of the LEL.

A maximum of one 5-gal canister of compressed propane will be present at the 306E Laboratory test location for purposes of performing these tests at any given time. All storage, handling, and use of propane will be in accordance with the standards set forth in Title 29, Part 1910.110 of the *Code of Federal Regulations* (29 CFR 1910.110) for liquified petroleum gases. Requirements of 29 CFR 1910.110 include the following:

- Specified piping and fittings
- Container standards
- Proper marking and identification of storage containers.

Personnel working with the propane will wear goggles for eye protection and gloves to prevent frostbite.

The test setup is a closed system with no direct connection to the sewer system. Prior to disposal of the water to the sewer system, propane concentrations shall be below 100 ppm (approximately 1% of LEL).

7.0 QUALITY ASSURANCE

The activities described in this test plan have been determined to be impact level QS activities. The following quality assurance requirements are consistent with this determination.

7.1 WITNESSING OF TESTS

Quality assurance witness is not required for any of the test activities described in this test plan.

7.2 INSTRUMENT CALIBRATIONS

All instrumentation used for the test activities described in this test plan shall be calibrated in accordance with manufacturer's specifications or WHC procedures prior to use or shall be calibrated by the manufacturer prior to receipt.

7.3 LICENSING REQUIREMENTS

No licensing requirements are applicable to the activities described in this test plan.

8.0 ORGANIZATION AND FUNCTION RESPONSIBILITIES

The organizations responsible for conducting Stanford In-Well Vapor Stripping System test activities are described below.

8.1 306E LABORATORY ORGANIZATION

The 306E Laboratory Organization is responsible for conducting all test activities described in this test plan in accordance with the test procedures provided in Chapter 5.0. The 306E Laboratory is also responsible for the detailed design and fabrication of the Stanford system prototype, the circulation well mockup, and the well packer test bed.

8.2 WHC GEOSCIENCES

WHC Geosciences is responsible for the overall direction of the Stanford in-well vapor stripping system test, including preparation and revision of the test plan, test procedures, and test report.

9.0 SCHEDULE

The current schedule for the Stanford In-Well Vapor Stripping System Tests calls for all test activities to be completed by May 18, 1994. The schedule for the individual activities that support this overall completion date is outlined below.

9.1 DESIGN, PROCURE AND FABRICATE STANFORD LABORATORY TEST SYSTEM

The test well assembly and all supporting equipment and instrumentation will be designed, procured, and installed by May 11, 1994. These activities are the responsibility of WHC Geosciences and the 306E Laboratory personnel.

9.2 PERFORM LABORATORY TESTS

The test activities described in this workplan will be performed by the 306E Laboratory with oversight from WHC Geosciences during the period from May 11, 1994 to June 30, 1994.

9.3 ANALYZE TEST DATA AND PREPARE REPORT

Test data will be analyzed and a draft report will be prepared by September 30, 1994.

10.0 REPORTS

A written report documenting test activities performed and the results of the tests will be prepared when all testing activities are complete. This test report will be released as a separate WHC Environmental Division supporting document. Copies of as-performed test procedures will be included as an appendix to the final report.

11.0 REFERENCE

Gvirtzman and Gorelick, 1992, "The Concept of In-Situ Vapor Stripping for Removing VOCs from Groundwater," *Transport in Porous Media*, 8:71-92, 1992, Kluwer Academic Publishers, the Netherlands.

ATTACHMENT 1: DATA SHEETS

1.0 PACKER TEST

Time test initiated: _____

Sand Added: (Y / N)

Recorded Observations:

TIME:	LEAKAGE OBSERVED (Y/N)	REMARKS

2.0 GENERAL TEST DATA SHEET

Diffuser Tested:_____ Date:_____

General Test Conditions (e.g., simulated aquifer, propane injection, head/lift combinations to be tested):

_____
_____
_____
_____
_____

2.1 INITIAL CONDITIONS SATISFIED

Stanford system installed in well mockup? (Y / N)

Diffuser installed in Stanford system? (Y / N)

All system valves closed? (Y / N)

Main well filled with water to static water level? (Y / N)

Water in surge tank equilibrated with well? (Y / N)

(If propane will be used) Ventilation system operating and providing adequate ventilation to the surge tank? (Y / N)

2.2 VERIFY INSTRUMENT CALIBRATIONS

Air Flowmeter calibrations current? (Y / N)
Calibration date:_____ Equipment serial number _____

Temperature gauge calibrations current? (Y / N)
Calibration date:_____ Equipment serial number _____

Pressure gauge calibrations current? (Y / N)
Calibration date:_____ Equipment serial number _____

Pressure transducer calibrations current? (Y / N)
Calibration date:_____ Equipment serial number_____

Datalogger calibration current? (Y / N)
Calibration date:_____ Equipment serial number _____

Combustible gas meter calibration current? (Y / N)
Calibration date:_____ Equipment serial number _____

Table 1. System Readings

Date/Time	Air Flows ft^3/min		Air Temps (^oC)		Air Wet Bulb Temps (^oC)		Liquid Flow Rates (gal/min)	
	Supply	Exhaust	Supply	Exhaust	Supply	Exhaust	Supply Meter	Weir Reading

Pressure Transducer and Temperature Readings													
10 ft		15 ft		25 ft		35 ft		45 ft		55 ft		65 ft	
T(^oC)	P	T(^oC)	P	T(^oC)	P	T(^oC)	P	T(^oC)	P	T(^oC)	P	T(^oC)	P
NA				NA				NA					

Water Level and Flow Weir Transducer				Propane Flow (L/hr)	Exhaust GCM Rdg	CGM Rdng in Surge Tank
Static level (ft)	Operating level lower Sn (ft)	Operating level	Weir Transducer			

Comments and observations (flow regime, samples collected, photographs taken)