ENCLOSURE

#1

§ 1009.6 Dissemination of prices and charges.

Current prices and charges for specific materials and services are available from the DOE laboratory or office providing the material or service, or from the responsible program office. If this office cannot be determined, inquiries regarding the appropriate contact office should be addressed to the Office of Finance and Accounting, Product Accounting and Pricing Branch, Mail Station 4A-139, 1000 Independence Avenue, SW., Washington, DC 20585.

PART 1010—CONDUCT OF EMPLOYEES

Sec.
1010.101 General.
1010.102 Cross-references to employee ethical conduct standards, financial disclosure regulations, and other conduct rules.
1010.103 Reporting wrongdoing.
1010.104 Cooperation with the Inspector General.

AUTHORITY: 5 U.S.C. 301, 302, 7301; 5 U.S.C. App. (Inspector General Act of 1978); 18 U.S.C. 208; E.O. 12674, 54 FR 15159, 3 CFR, 1989 Comp., p. 215, as modified by E.O. 12731, 55 FR 42547, 3 CFR, 1990 Comp., p. 306.

SOURCE: 61 FR 35088, July 3, 1996, unless otherwise noted.

§ 1010.101 General.

This part applies to employees of the Department of Energy (DOE), excluding employees of the Federal Energy Regulatory Commission.

§ 1010.102 Cross-references to employee ethical conduct standards, financial disclosure regulations, and other conduct rules.

Employees of DOE are subject to the Standards of Ethical Conduct for Employees of the Executive Branch at 5 CFR part 2635, the DOE regulation at 5 CFR part 3301 which supplements the executive branch-wide standards, the executive branch-wide financial disclosure regulations at 5 CFR part 2634, the executive branch-wide financial interests regulations at 5 CFR part 2640, and the executive branch-wide employee responsibilities and conduct regulation at 5 CFR part 735.

[61 FR 35088, July 3, 1996, as amended at 63 FR 30111, June 3, 1998]

§ 1010.103 Reporting wrongdoing.

(a) Employees shall, in fulfilling the obligation of 5 CFR 2635.101(b)(11), report fraud, waste, abuse, and corruption in DOE programs, including on the part of DOE employees, contractors, subcontractors, grantees, or other recipients of DOE financial assistance, to the Office of Inspector General or other appropriate Federal authority.

(b) All alleged violations of the ethical restrictions described in section 1010.102 that are reported in accordance with (a) of this section to an appropriate authority within the Department shall in turn be referred by that authority to the designated agency ethics official or his delegatee, or the Inspector General.

§ 1010.104 Cooperation with the Inspector General.

Employees shall respond to questions truthfully under oath when required, whether orally or in writing, and must provide documents and other materials concerning matters of official interest. An employee is not required to respond to such official inquiries if answers or testimony may subject the employee to criminal prosecution.

PART 1013—PROGRAM FRAUD CIVIL REMEDIES AND PROCEDURES

Sec.
1013.1 Basis and purpose.
1013.2 Definitions.
1013.3 Basis for civil penalties and assessments.
1013.4 Investigation.
1013.5 Review by the reviewing official.
1013.6 Prerequisites for issuing a complaint.
1013.7 Complaint.
1013.8 Service of complaint.
1013.9 Answer.
1013.10 Default upon failure to file an answer.
1013.11 Referral of complaint and answer to the ALJ.
1013.12 Notice of hearing.
1013.13 Parties to the hearing.
1013.14 Separation of functions.
1013.15 *Ex parte* contacts.
1013.16 Disqualification of reviewing official or ALJ.

U.S. Department of Energy
Washington, D.C.

ORDER

DOE O 221.1

Approved: 03-22-01
Sunset Review: 03-22-03
Expires: 03-22-05

SUBJECT: REPORTING FRAUD, WASTE, AND ABUSE TO THE OFFICE OF INSPECTOR GENERAL

1. OBJECTIVE. To establish policies and procedures for reporting fraud, waste, abuse, misuse, corruption, criminal acts, or mismanagement to the Department of Energy (DOE), Office of Inspector General (OIG).

2. CANCELLATION. DOE 2030.4B, REPORTING FRAUD, WASTE, AND ABUSE TO THE OFFICE OF INSPECTOR GENERAL, dated 5-18-92. Cancellation of this Order does not, by itself, modify or otherwise affect any contractual obligations to comply with the Order. Canceled Orders that are incorporated by reference in a contract will remain in effect until the contract is modified to delete the reference to the requirements in the canceled Orders.

3. APPLICABILITY.

   a. DOE Elements. This Order applies to all DOE Headquarters and field elements, including the National Nuclear Security Administration (NNSA).

   b. Contractors. This Order applies to all DOE major facilities management contractors and all other contractors as contractually mandated. Contractor requirements are listed in the Contractor Requirements Document (CRD), Attachment 1. Contractors are responsible for—

      (1) compliance with the requirements of the CRD of this Order regardless of the performer of the work, and

      (2) flowing down the requirements of the CRD of this Order to subcontracts to the extent necessary to ensure contractors' compliance with the requirements.

4. POLICY.

   a. The OIG shall seek to uncover fraud, waste, abuse, misuse, corruption, criminal acts, or mismanagement relating to DOE programs, operations, facilities, contracts, and information technology systems, and ensure that corrective action is taken. When

Distribution:
All Departmental Elements

Initiated By:
Office of Inspector General

appropriate, referral of allegations/information shall be made by the OIG to other appropriate law enforcement entities, prosecutors, other DOE components, or other agencies.

b. Employees of DOE and its contractors who have information about actual or suspected violations of law, regulations, or policy including fraud, waste, abuse, misuse, corruption, criminal acts, or mismanagement relating to DOE programs, operations, facilities, contracts, or information technology systems shall immediately notify the appropriate authorities. Notwithstanding the above, employees should, when appropriate, report directly to the OIG any information concerning alleged wrongdoing by DOE; its contractors, subcontractors, grantees, or other recipients of DOE financial assistance; or their employees.

c. DOE managers and contractor managers must ensure that reprisals are not taken against their employees who report fraud, waste, abuse, misuse, corruption, criminal acts, or mismanagement.

5. RESPONSIBILITIES.

a. Office of Inspector General

(1) Notifies all DOE employees, at least annually, of their duty to report allegations of fraud, waste, abuse, misuse, corruption, criminal acts, or mismanagement relating to DOE programs, operations, facilities, contracts, or information technology systems, as well as, of OIG responsibilities in this area.

(2) Operates and publicizes a telephone hotline to permit individuals/entities to report allegations of fraud, waste, abuse, misuse, corruption, criminal acts, or mismanagement relating to DOE programs, operations, facilities, contracts, or information technology systems to the OIG.

(3) Processes allegations in accordance with OIG operations and procedures.

(4) Disseminates to the Lead Program Secretarial Office (LPSO) for their respective facilities and organizations, procedures for reporting allegations of fraud, waste, misuse, abuse, corruption, criminal acts, or mismanagement relating to operations, facilities, contracts, or information technology systems. Also, disseminates these procedures to all applicable DOE contracting officers for further dissemination to DOE contractors, including contractors of NNSA, and their employees.

(5) Designates an OIG representative for each DOE facility or site, and ensures that the Inspector General representative communicates regularly and on a timely basis with the applicable DOE officials at that facility or site.

(6) Notifies the Director of Security Affairs (SO-20) and the Chief of Defense Nuclear Security, as appropriate, of allegations involving the security of special nuclear material, classified computer systems, and classified information.

(7) Notifies the Deputy Administrator for Naval Reactors (NR-1), as appropriate, of allegations involving the security of special nuclear material or classified or sensitive information under that office's cognizance.

(8) Notifies the Chief Information Officer (SO-30), as appropriate, of allegations relating to the security of unclassified computer systems and sensitive unclassified automated information.

(9) Notifies the Director of Counterintelligence (CN-1)/Chief of Defense Nuclear Counterintelligence, as appropriate, of allegations regarding espionage, including approaches made by representatives of other governments for the commission of espionage or the collection of information.

(10) Notifies the DOE Designated Agency Ethics Official (GC-80), as appropriate, of alleged violations of Standards of Conduct.

(11) Notifies the Deputy Assistant Secretary for Oversight (EH-2), as appropriate, of allegations concerning environmental, safety, or health operational hazards.

(12) Notifies appropriate Heads of Departmental Elements of allegations involving matters under their purview, unless the OIG determines that such notification might jeopardize the successful progress or completion of an inquiry.

b. Heads of All Field Elements, the Administrator for Nuclear Security, and the Director, Office of Management and Administration (MA-1), must ensure that the OIG hotline telephone number is:

(1) Displayed in common areas under their cognizance, such as cafeterias, public telephone areas, official bulletin boards, reception rooms, and building lobbies.

(2) Published in telephone books and employee newsletters under their cognizance.

c. Heads of All Field Elements, the Administrator for Nuclear Security, and the Director, Office of Procurement and Assistance Management (MA-5), must ensure that:

(1) Contractors under their cognizance are required to notify their employees annually of their duty to report allegations of fraud, waste, abuse, misuse, corruption, criminal acts, or mismanagement relating to DOE programs, operations, facilities, contracts, or information technology systems to the appropriate authorities. The annual notification shall include the provision that, notwithstanding the above, DOE contractor employees should, when appropriate, report directly to the OIG any information concerning alleged wrongdoing by DOE; its contractors, subcontractors, grantees, or other recipients of DOE financial assistance; or their employees.

(2) Contractors under their cognizance are required to display the OIG hotline telephone number in common areas of buildings, such as cafeterias, public telephone areas, official bulletin boards, reception rooms, and building lobbies.

(3) Contractors under their cognizance are required to publish the OIG hotline telephone number in telephone books and newsletters under the contractor's cognizance.

(4) All alleged violations of law, regulations, or policy, including incidents of fraud, waste, abuse, misuse, corruption, criminal acts, or mismanagement which have been referred to Federal, State, or local law enforcement entities are also reported to the OIG within a reasonable period of time, but not later than 24 hours.

d. Employees of DOE and its contractors must:

(1) Report actual or suspected violations of law, regulations, or policy including fraud, waste, abuse, misuse, corruption, criminal acts, or mismanagement relating to DOE programs, operations, facilities, contracts, or information technology systems to the appropriate authorities. Notwithstanding the above, employees should, when appropriate, report directly to the OIG any information concerning alleged wrongdoing by DOE; its contractors, subcontractors, grantees, or other recipients of DOE financial assistance; or their employees.

(2) Report to the OIG any allegations of reprisals taken against employees who have reported fraud, waste, abuse, misuse, corruption, criminal acts, or mismanagement relating to DOE programs, operations, facilities, contracts, or information technology systems.

6. REFERENCES.

a. The Inspector General Act of 1978, Public Law 95-452, as amended, 5 United States Codes (U.S.C.), App. 3, sets forth authority and functions of the Inspector General.

b. Public Law 101-12, Whistleblower Protection Act of 1989, which strengthens the protection available to Federal employees against prohibited personnel practices.

c. Title 10 CFR Part 1010, Conduct of Employees, which requires an employee to report fraud, waste, abuse, and corruption in DOE programs.

d. Title 18, Federal Criminal Code and Rules, Crimes and Criminal Procedures, as amended, which prescribes rules that govern all criminal procedures in the courts of the United States.

e. Executive Order 12333, "United States Intelligence Activities," dated 12-4-81, which designates the Department of Energy as a member of the Intelligence Community.

f. Executive Order 12863, "President's Foreign Intelligence Advisory Board," dated 9-13-93, which establishes intelligence reporting requirements for the OIG.

g. Executive Order 12344, "Naval Nuclear Propulsion Program," dated 1-27-82, which preserves the basic structure, policies, and practices developed for the program in the past and establishes additional policies, organization, and administrative procedures to ensure that the program will continue to function with excellence.

h. Executive Order 12731, "Principles of Ethical Conduct for Government Officers and Employees," dated 10-17-90, which establishes the requirement for Government employees to disclose fraud, waste, abuse, and corruption.

i. DOE N 205.1, UNCLASSIFIED COMPUTER SECURITY PROGRAM, dated 7-26-99, which establishes requirements, policies, responsibilities, and procedures for developing, implementing, and sustaining a DOE unclassified computer security program.

j. DOE O 221.2, COOPERATION WITH THE OFFICE OF INSPECTOR GENERAL, dated 03/22/01, which establishes DOE policy for cooperating with the OIG.

k. DOE O 471.1A, IDENTIFICATION AND PROTECTION OF UNCLASSIFIED CONTROLLED NUCLEAR INFORMATION, dated 6-30-00, which establishes policy and procedures for identifying Unclassified Controlled Nuclear Information (UCNI) and for reviewing and marking documents and material containing UCNI.

7. CONTACT. Questions concerning this Order should be addressed to the Office of Inspector General, 202-586-3202.

SPENCER ABRAHAM
SECRETARY OF ENERGY

CONTRACTOR REQUIREMENTS DOCUMENT

DOE O 221.1, REPORTING FRAUD, WASTE, AND ABUSE TO THE OFFICE OF INSPECTOR GENERAL

DOE contractors, including National Nuclear Security Administration (NNSA) contractors, or their employees who have information about actual or suspected violations of law, regulations, or policy including fraud, waste, abuse, misuse, corruption, criminal acts, or mismanagement relating to DOE programs, operations, facilities, contracts, or information technology systems shall immediately notify the appropriate authorities. When appropriate, DOE contractors and their employees should report directly to the OIG any information concerning alleged wrongdoing by DOE employees; its contractors, subcontractors, grantees, or other recipients of DOE financial assistance; or their employees.

1. Contractor managers must ensure that reprisals are not taken against DOE contractor employees who report fraud, waste, abuse, misuse, corruption, criminal acts, or mismanagement.

2. Contractors and their employees are also required to—

   a. Notify their employees annually of their duty to report allegations of fraud, waste, abuse, misuse, corruption, criminal acts, or mismanagement relating to DOE programs, operations, facilities, contracts, or information technology systems to appropriate authorities. The notification shall include the provision that employees should, when appropriate, report directly to the OIG any information concerning alleged wrongdoing by DOE employees; its contractors, subcontractors, grantees, or other recipients of DOE financial assistance; or their employees.

   b. Display the OIG hotline telephone number in common areas of buildings, such as cafeterias, public telephone areas, official bulletin boards, reception rooms, and building lobbies.

   c. Publish the OIG hotline telephone number in telephone books and newsletters under the contractor's cognizance.

   d. Report to the OIG any allegations of reprisals taken against employees who have reported fraud, waste, abuse, misuse, corruption, criminal acts, or mismanagement relating to DOE programs, operations, facilities, contracts, or information technology systems.

   e. Report to the OIG within a reasonable period of time, but not later than 24 hours, all alleged violations of law, regulations, or policy, including incidents of fraud, waste, abuse, misuse, corruption, criminal acts, or mismanagement which have been referred to Federal, State, or local law enforcement entities.

U.S. Department of Energy
Washington, D.C.

NOTICE

DOE N 221.10

Approved: 9-15-04
Expires: 9-15-05

SUBJECT: REPORTING FRAUD, WASTE, AND ABUSE

1. PURPOSE. To notify all Department of Energy (DOE) employees, including National Nuclear Security Administration (NNSA) employees, of their duty to report allegations of fraud, waste, and abuse to the appropriate authorities, including the DOE Office of Inspector General (OIG).

2. REFERENCES. DOE O 221.1, *Reporting Fraud, Waste, and Abuse to the Office of Inspector General*, dated 3-22-01, which establishes policies and procedures for reporting fraud, waste, and abuse to the appropriate authorities, including the DOE OIG.

3. GUIDELINES FOR REPORTING FRAUD, WASTE, AND ABUSE.

   a. Any employee who has information about alleged criminal violations relating to DOE programs, operations, funds, contracts, grants, or information technology systems shall provide this information to the OIG. Examples of such violations include, but are not limited to: false statements; false claims; bribery; kickbacks; fraud; DOE environmental, safety, and health violations; theft; computer crimes; and conspiracy to commit any of these acts.

   b. The above reporting requirement does not apply to information about espionage. Information regarding espionage, including approaches made by representatives of other governments for the commission of espionage or the collection of information, should be reported to the Director of Counterintelligence for DOE or the Director of Defense Nuclear Counterintelligence for NNSA, as appropriate.

   c. Noncriminal violations normally should be reported through the supervisory chain. Also, violations of the DOE Standards of Conduct may be reported to the Ethics Counselor in DOE's Office of the General Counsel. In addition, employees may report alleged noncriminal violations of the Standards of Conduct directly to the OIG.

   d. Notwithstanding any other provision, employees must, when appropriate, report any information concerning wrongdoing directly to the OIG.

e. One avenue for reporting information to the OIG is via the OIG Hotline. The OIG Hotline may be reached at:

1-800-541-1625 (toll free)
202-586-4073 (commercial)
202-586-4902 (fax)
ighotline@hq.doe.gov (email)
U.S. Department of Energy (mail)
Office of Inspector General
Attn: IG-40
Mail Stop 5D031
1000 Independence Ave., SW
Washington, DC 20585

BY ORDER OF THE SECRETARY OF ENERGY:

KYLE E. McSLARROW
Deputy Secretary

ENCLOSURE

#2

Table 1. QA Oversight Related to Issues Raised in E-Mails				
E-Mail Issue/QA Requirement Violated	**Assessment Activity**	**Related Deficiency Documents**	**Resolution**	**Notes**
1. Air Temperature – No data tracking numbers Lack of data traceability and use of correct air temperature value. Criteria – QARD, Rev. 8, Supplement III, data traceability shall be maintained.	M&O-ARP-00-04	USGS-00-D-034	USGS analysis and model reports (e.g., the Infiltration Model Analysiis Modeling Report (AMR) and the Infiltration Uncertainty AMR) were revised to improve traceability and transparency.	None
2. Lack of qualified data. Use of unqualified data and lack of data traceability. Criteria – QARD, Rev. 8, Supplement III, data shall be traceable to its qualification status and data shall be qualified.	M&O-ARP-00-04	USGS-00-D-034	Unqualified data were tracked and qualified. USGS analysis and model reports (e.g., the Infiltration Model AMR and the Infiltration Uncertainty AMR) were revised to improve traceability and transparency.	Audit M&O-ARP-00-04 reviewed output from the infiltration model. Condition Report (CR)-5071 was issued 3/14/2005 to address that the Infiltration Model AMR control files were not in the Technical Data Information Form. Missing control files are being located in response to CR-5071.

Table 1. QA Oversight Related to Issues Raised in E-Mails				
E-Mail Issue/QA Requirement Violated	**Assessment Activity**	**Related Deficiency Documents**	**Resolution**	**Notes**
3. Mean annual precipitation and mean annual temperature data was used in the Viability Assessment. Future climate analysis used these values before they were generated by the net infiltration model. Criteria – QARD, Rev. 8, Supplement III, data shall be identified in a manner that facilitates traceability to associated documentation.	M&O-ARP-00-04	USGS-00-D-034	USGS analysis and model reports (e.g., the Infiltration Model AMR and the Infiltration Uncertainty AMR)) were revised to improve data traceability and transparency.	None

Table 1. QA Oversight Related to Issues Raised in E-Mails				
E-Mail Issue/QA Requirement Violated	**Assessment Activity**	**Related Deficiency Documents**	**Resolution**	**Notes**
4. Software programs were not on the baseline or were otherwise improperly documented. Criteria – QARD, Rev. 8, Supplement I, software shall be documented sufficiently to demonstrate the ability to meet specified needs.	M&O-ARP-00-04	LVMO-00-D-039	Software products were reviewed to ensure that procedural controls to that software were being applied. Software documentation errors were corrected. Identified software products requiring qualification were qualified and tracked through the software configuration management process.	At the time of the audit, use of software routines was allowed to be documented and qualified in the technical products. Corrections were made to the documentation supporting these routines to permit calculation by hand without recourse to the originator. Subsequent to these corrections, software requirements were changed to required routines to be handled in the same manner as software codes (i.e., they had to be qualified and added to the baseline). Legacy retesting is ongoing to verify that these codes produce results as designed.

Table 1. QA Oversight Related to Issues Raised in E-Mails				
E-Mail Issue/QA Requirement Violated	**Assessment Activity**	**Related Deficiency Documents**	**Resolution**	**Notes**
5. Seven climate input files were non Q.... Criteria: QARD, Rev. 8, Supplement III, data shall be qualified and identified in a manner that facilitates traceability to associated documentation.	M&O-ARP-00-04	USGS-00-D-034	Unqualified data were tracked and qualified. USGS analysis and model reports (e.g., the Infiltration Modell AMR and the Infiltration Uncerttainty AMR) were revised to improwe traceability to qualification status and to improve transparency.	Audit M&O-ARP-00-04 reviewed output from the infiltration model.
6. Station 4JA and Area 12 precipitation files (output from Paradox database) used as input to MARKOV code had the last four lines deleted. Criteria: QARD, Rev. 8, Supplement III, identification and traceability of data shall be maintained, and Supplement V, electronic data shall be controlled to ensure completeness of the data.	Not addressed	Not addressed	Not applicable	Available precipitation records from the Nevada Test Site stations 4JA and Area 12 were used in the 100-yr daily climate input files for present-day climate scenarios using MARKOV 1.0 and PPTSIM 1.0 codes. These records differed from the originals with regard to the last four lines. This issue was not identified through oversight activities.

Table 1. QA Oversight Related to Issues Raised in E-Mails				
E-Mail Issue/QA Requirement Violated	**Assessment Activity**	**Related Deficiency Documents**	**Resolution**	**Notes**
7. No scientific notebook The planning documentation identified that a scientific notebook would be used. Criteria: QARD, Rev. 8, Supplement III, scientific investigations shall be performed using scientific notebooks or implementing documents.	M&O-ARP-00-04	USGS-00-D-034	The Infiltration Model AMR was revised to include the level of detail necessary to support the work (consistent with what would typically be provided in a scientific notebook).	None

Table 1. QA Oversight Related to Issues Raised in E-Mails				
E-Mail Issue/QA Requirement Violated	**Assessment Activity**	**Related Deficiency Documents**	**Resolution**	**Notes**
8. Non-Q software, TRANSFORM and CORPSCOM, used to generate files Dem-box.utm and Dem-box.geo. Criteria: QARD, Rev. 8, Supplement I, use of software shall be controlled and documented to ensure compliance with specified requirements.	M&O-ARP-00-04	LVMO-00-D-038	Software products were reviewed to ensure that procedural controls to that software were being applied. Software documentation errors were corrected. Identified software products requiring qualification were qualified and tracked through the software configuration management process. Exempt software was identified and tracked.	The files Dem-box.utm and Dem-box.geo were not used in the AMR. CR 4196, issued 11/23/2004, evaluated the categorization of several codes as exempt.

Table 1. QA Oversight Related to Issues Raised in E-Mails				
E-Mail Issue/QA Requirement Violated	**Assessment Activity**	**Related Deficiency Documents**	**Resolution**	**Notes**
9. Blocking ridge numbers calculated using BLOCK7R do not match the file 30msite.inp Criteria: QARD, Rev. 8, Supplement I, software shall be validated for its intended use.	M&O-ARP-00-04	LVMO-00-D-039	Software products were reviewed to ensure that procedural controls to that software were being applied. Software documentation errors were corrected. Identified software products requiring qualification were qualified and tracked through the software configuration management process.	At the time of the audit, use of software routines was allowed to be documented and qualified in the technical product. Corrections were made to the documentation supporting these routines to permit calculation by hand without recourse to the originator. Subsequent to these corrections, software requirements were changed to require routines to be handled in the same manner as software codes (i.e., they had to be qualified and added to the baseline). Legacy retesting is ongoing to verify that these codes produce results as designed.

Table 1. QA Oversight Related to Issues Raised in E-Mails				
E-Mail Issue/QA Requirement Violated	**Assessment Activity**	**Related Deficiency Documents**	**Resolution**	**Notes**
10. File Mod3-ppt.dat was stopped in day 274 in 1995. It did not include pre-1987 interpolation and post 1995 data. The software file is an Excel file using a standard linear interpolation method. Inclusion of this additional data would provide a more accurate representation and would reduce conservatism. Criteria: No specific QA requirement was violated. QARD, Supplement III requirements apply to use of data.	Not addressed	Not addressed	Not applicable	The file Mod3-ppt.dat is a daily climate input file developed for model calibration and present-day climate simulations using available precipitation records from monitoring sites within the study area and in the proximity of Yucca Mountain. This is a technical issue related to level of conservatism.

Table 1. QA Oversight Related to Issues Raised in E-Mails				
E-Mail Issue/QA Requirement Violated	**Assessment Activity**	**Related Deficiency Documents**	**Resolution**	**Notes**
11. Inadequate documentation in the AMR of software routines. The routine VEGCOV01 was run with option 2 to generate the file 30mgrd02.sr1 from file 30mgrd01. This caused the vegetation estimate to be based on a non representative vegetation type. Vegetation types from the regional model were made into all the watershed files. These files were output to CHNNET16 V. 1.0. Criteria: QARD, Rev. 8, Supplement I, control and use of software shall be documented.	M&O-ARP-00-04	LVMO-00-D-039	Software products were reviewed to ensure that procedural controls to that: software were being applied. Software documentation errors were corrected.	This issue has no impact on the use of data because these two codes were not explicity used to generate input for the Infiltration Model AMR. The routines moved forward as codes were retested or scheduled for legacy retesting in accordance with LP-14Q-BSC. Retesting ensures the code runs as designed.

Table 1. QA Oversight Related to Issues Raised in E-Mails				
E-Mail Issue/QA Requirement Violated	**Assessment Activity**	**Related Deficiency Documents**	**Resolution**	**Notes**
12. Cannot reproduce block ridge numbers with BLOCK7R. Inadequate documentation in the AMR of software routines. Criteria: QARD, Rev. 8, Supplement I, software provide correct results for a specified range of input parameters.	M&O-ARP-00-04	LVMO-00-D-039	Software products were reviewed to ensure that procedural controls to that software were being applied. Software documentation errors were corrected.	At the time of the audit, use of software routines was allowed to be documented and qualified in the technical product. Corrections were made to the documentation supporting these routines to permit calculation by hand without recourse to the originator. Subsequent to these corrections, software requirements were changed to required routines to be handled in the same manner as software codes (i.e., they had to be qualified and added to the baseline). Legacy retesting is ongoing to verify that these codes produce results as designed.

Table 1. QA Oversight Related to Issues Raised in E-Mails				
E-Mail Issue/QA Requirement Violated	**Assessment Activity**	**Related Deficiency Documents**	**Resolution**	**Notes**
13. Elevation problem. No QA requirement could be identified from the limited information in the e-mail.	Not addressed	Not addressed	Not applicable	Not enough information to track.
14. Software Bug in top layer of cascading bucket model. Criteria: QARD, Rev. 8, Supplement I, software verification shall ensure that established requirements are met.	M&O-ARP-00-04	LVMO-00-D-039	Software products were reviewed to ensure that procedural controls to that software were being applied. Software documentation errors were corrected.	None
15. Soil ks conversion off by a factor of 10. Criteria: QARD, Rev. 8, Supplement III, data shall be identified to facilitate traceability to associated documentation.	Not addressed	Not addressed	Not applicable	Selection of parameter values is a technical activity. Traceability of data is a QA issue.

Table 1. QA Oversight Related to Issues Raised in E-Mails				
E-Mail Issue/QA Requirement Violated	**Assessment Activity**	**Related Deficiency Documents**	**Resolution**	**Notes**
16. Inadequate documentation in the AMR of software routines. Strange integer for rock type (1.33) in retesting GEOMAP7. Criteria: QARD, Rev. 8, Supplement I, software provides correct results for a specified range of input parameters.	M&O-ARP-00-04	LVMO-00-D-039	Software products were reviewed to ensure that procedural controls to that software were being applied. Software documentation errors were corrected.	At the time of the audit, use of software routines was allowed to be documented and qualified in the technical product. Corrections were made to the documentation supporting these routines to permit calculation by hand without recourse to the originator. Subsequent to these corrections, software requirements were changed to required routines to be handled in the same manner as software codes (i.e., they had to be qualified and added to the baseline). Legacy retesting is ongoing to verify that these codes produce results as designed.

Table 1. QA Oversight Related to Issues Raised in E-Mails				
E-Mail Issue/QA Requirement Violated	**Assessment Activity**	**Related Deficiency Documents**	**Resolution**	**Notes**
17. Installation of unqualified software: SURFER V6.04, TRANSFORM V3.3, ARCINFO V6.12, ARCVIEW V.3.1 Criteria: QARD, Rev. 8, Supplement 1, software qualification requirements must be met prior to use.	M&O-ARP-00-04	LVMO-00-D-038	Software products were reviewed to ensure that procedural controls to that software were being applied. Software documentation errors were corrected.	The routines moved forward as codes were retested or scheduled for legacy retesting in accordance with LP-14Q-BSC. Retesting ensures the code runs as designed. SURFER and TRANSFORM were documented as routines. ARCINFO V6.1.2 was replaced by V7.2.1, which was qualified. ARCVIEW was controlled under section 5.11 of AP-SI.1Q. These four codes were subsequently identified as exempt in the final version of the Infiltration Model AMR. CR 4196, issued 11/23/2004, evaluated the categorization of several codes as exempt.

ENCLOSURE

#3

MOL.20000331.0610

United States Department of the Interior

U. S. GEOLOGICAL SURVEY
Box 25046 M.S. 421
Denver Federal Center
Denver, Colorado 80225

QA: QA
September 29, 1999

IN REPLY REFER TO:

MEMORANDUM

TO: Chief, Engineering Assurance Group, Yucca Mountain Project Branch, U.S. Geological Survey, MS 421, Denver, CO

FROM: For Chief, Yucca Mountain Project Branch, U.S. Geological Survey, Las Vegas, NV

SUBJECT: Rescission of Quality Management Procedures

The following procedures are rescinded and replaced by DOE/OCRWM's Administrative Procedures as a result of the new Quality System Process Validation and Re-engineering activity:

QMP-2.02, Federal Personnel Qualification
QMP-2.07, Training
QMP-2.08, Non-Federal Personnel Qualification
QMP-3.03, Software
QMP-3.04, Review and Approval of YMP-USGS Data, Interpretations of Data, and Manuscripts
QMP-5.05, Scientific Notebook
QMP-12.01 Instrument Calibration

These rescissions will be effective upon final concurrence signature.

CONCURRENCE:

Assistant Chief Hydrologist for Information
L. V. Wade — Date: 9/29/99

Senior Advisor for Science Applications
J. F. Devine — Date: 10/12/99

DOE/OCRWM Office of Quality Assurance Representative
D. J. Sinks — Date: 12/17/99

Copies to: A. Anderson, USGS, Denver, CO
A. E. Lykins, USGS, Denver, CO
M. H. Mustard, USGS, Denver, CO

MANAGEMENT PROCEDURES MANUAL

CHAPTER 3 - SCIENTIFIC INVESTIGATION AND DESIGN CONTROL

SECTION 3 - SOFTWARE

1. PURPOSE. This Quality Management Procedure (QMP) establishes the software quality assurance (QA) activities for controlling and documenting the development, modification, acquisition, and application of software by the U.S. Geological Survey (USGS), Yucca Mountain Project Branch (YMPB). The procedure also describes organizational responsibilities, Software Life Cycle requirements, and Software Configuration Management (SCM) activities for the YMPB. Therefore, this QMP constitutes the Software Quality Assurance Plan (SQAP).

2. SCOPE OF COMPLIANCE. This Quality Management Procedure (QMP) applies to quality-affecting software developed or acquired by YMPB personnel for site characterization activities. Software used for the Scientific Expert Elicitation under QMP-3.16 is exempt from this QMP. Software that is employed as an integral part of measuring and test equipment is controlled by QMP-12.01 and is exempt from this QMP. The following types of software do not fall within the scope of this QMP:

   - Operating systems, system utilities, and compilers, and their associated libraries;
   - Administrative and management systems; and
   - Software that does not generate data (as defined by QMP-3.04), such as word processing programs, spreadsheets, data-base managers, graphing and visual display software, and statistical analysis programs. However, applications written for use within these types of software may need to meet the requirements of this QMP.

   As of the effective date of Revision 6 of this QMP (7/15/96), software with a released status was authorized for continued YMPB use. Software without a released status shall meet the requirements of this QMP prior to the formal release of the data or interpretations of data resulting from the use of the software. Software whose use has been completed but whose products are not yet released (e.g. a report still in process) as of the effective date of Revision 6 of this QMP is exempt from these requirements.

3. DEFINITIONS. For the purpose of this procedure, the following definitions shall prevail.

   3.1 Acquired Software: Software developed by a source that is external to the YMPB.

   3.2 Affected Organization: An organization performing Yucca Mountain Project work subject to Quality Assurance Requirements and Description (QARD) DOE/RW-0333P, requirements whose organizational relationships are defined in Office of Civilian Radioactive Waste Management (OCRWM) Program documents.

3.3 Configuration Status Accounting: A system to develop and maintain records of the status of software as it moves through the software life cycle.

3.4 Functionality: The functions the software is to perform.

3.5 Performance: Accuracy and stability of solutions derived with code over total space and time domains appropriate for code, for full range of parameter values that might be encountered.

3.6 Primary User: The Site Characterization Plan (SCP) activity for which a Principal Investigator initiates or otherwise has principal responsibility for the development, modification, or application of the software.

3.7 Released Software: Software that is approved as having met all QMP requirements for use.

3.8 Software: Computer programs, procedures, rules, and associated documentation pertaining to the operation of a computer system.

3.9 Software Baseline: A document or software that has been formally reviewed and approved that thereafter serves as the basis for further development and that can be changed only through formal change control procedures. Baseline documents should identify software products (e.g., source code, object code, test cases) and software process specifications (e.g., standards and procedures) that are needed to establish and maintain stability of the software activities.

3.10 Software Configuration Management: A system of controls and authorizations for the purpose of a) identification and establishment, control of changes to, and release of baselines, b) recording the status of baselines, proposed changes, and implemented changes, c) reporting problems and associated corrective actions, and d) documenting the correctness and completeness of baselines.

3.11 Software Control Point: The point in the Life Cycle at which a baseline element is approved for release. Controls are applied to the use, modification, distribution, and retirement or withdrawal of the baseline elements.

3.12 Software Defect: An error in a computer code (synonymous with "bug") or a failure to meet one or more specifications of the software.

3.13 Software Life Cycle: A series of activities that begin when software is conceived and ends when the software is no longer available for use.

3.14 Software Validation: The process of testing a software system or component to determine whether it satisfies software requirement specifications, and ensuring the software a) correctly and adequately performs all intended functions, and b) does not perform any unin-

tended function (by itself or in combination with other functions) that can degrade the entire system.

3.15 Software Verification: The procedure to determine whether software products and processes satisfy conditions imposed at the start of a given Life Cycle phase.

3.16 Version: A variation of the original software code. A documented modification to a software program indicates a new version has been developed.

4. RESPONSIBILITIES.

4.1 The Chief, Earth Science Investigations Program, (ESIP), is responsible for ensuring the implementation of this QMP by ESIP personnel engaged in YMPB scientific investigations, studies, and activities. The Chief, ESIP, also is responsible for appointing members to the Software Overview Board.

4.2 The Team Chiefs, ESIP, are responsible for approval of the software baseline documents developed by their technical staff.

4.3 The Chief, Engineering Assurance Group, (EAG), is responsible for ensuring that all submitted software documentation satisfies the requirements set forth within this QMP. The Chief, EAG, also is responsible for Software Configuration Management; notifying software users of modifications, defects, or changes of status in released software; approving the withdrawal or retirement of software; and chairing the Software Overview Board.

4.4 The Principal Investigator, (PI), is responsible for assigning Technical Contacts for software. The Principal Investigator describes the application of software for site characterization activities on the Software Configuration form. The Principal Investigators ensures the preparation of software documents appropriate for software activities as discussed in Section 5. The PI also is responsible for submitting completed records to Project Records facilities.

4.5 The Technical Contact, (TC), has the responsibility for administering the Software Quality Assurance Plan procedures described in Section 5 of this QMP for his or her YMPB software.

4.6 Software Overview Board Chair has the responsibility for conducting the affairs of the Board in compliance with this procedure. The Chair also is responsible for assigning software identification numbers and documenting the results of the Board's decisions.

5. PROCEDURE.

The following procedure establishes the methods used in the YMPB to develop, use, modify, release, and withdraw/retire software, beginning with submittal of a Software Identification Form (SIF) to the Software Overview Board by the Technical Contact for the Primary User. The SIF (Attachment 1 or equivalent) identifies the software and YMPB Primary User associated with the software. The determination of the specific documentation and Life Cycle Plan requirements is made by the Software Overview Board after submission of the

For software that requires documentation under Sections 5.2, 5.3, or 5.4, the Software Overview Board Chair shall assign a unique software identification number to the software. Each version of software shall have a unique identifier. The SIF and the Software Configuration Management (SCM) form (Attachment 2) must be submitted prior to, or concurrent with, submittal of other baseline documents. The Software Overview Board shall return the SIF and SCM forms to the TC, with copies maintained by the Chief, EAG (or delegate). The unique software identification number shall be used to identify all documents and items associated with the software, and to provide a cross-reference to other software baseline documents in effect. It also shall be listed on all outputs, if feasible.

There are four possible levels of software documentation (Sections 5.1, 5.2, 5.3, and 5.4). Software shall be baselined with baseline elements entered in the Software Configuration Management (SCM) System as appropriate, and approved for release in accordance with the following sections.

5.1 Limited Requirements: Software that can be verified by visual inspection and/or hand calculations, shall have only limited requirements, including:

- listing of the baseline version (executable or source code) and any subsequent changes to the software, and
- documentation that the software provides correct results for a specified range of input parameters.

This software shall be considered released after approval of the SIF by the Software Overview Board. Software documentation required above shall be submitted under this QMP, or as supporting information under QMP-3.04, QMP-5.01, or QMP-5.05. The SIF shall indicate under which QMP the documentation will be submitted. Changes to the original version shall be documented using the same QMP as used for the initial version. A new SIF is required only when the method or location of documentation is changed. Software meeting the requirements of this section do not require a unique SCM identifier.

5.2 Full Software Life Cycle: Software developed or modified by the YMPB that cannot be verified by visual inspection and/or hand calculation requires documentation and approval of a full life cycle plan prior to release. Software Life Cycle implementation may be iterative or sequential in nature. For software being developed or modified, a SIF, SCM form, and a reviewed and approved Requirements Specification comprise the initial Life Cycle documentation for the software. Upon or before completion of the software development or modification, the Primary User shall submit baseline element documentation following the procedures for full life cycle software. Control points occur at the end of a Life Cycle phase, at which time the appropriate software baseline elements are documented. Life Cycle Plan activities and documentation include the following:

- Software Identification Form (SIF) (Attachment 1 or equivalent)
- Software Configuration Management (SCM) form (Attachment 2 or equivalent)
- Requirements Specification
- Validation Plan

- Design Description
- User Documentation
- Executable and source code
- Software Validation Report
- Review and verification documentation
- Documentation for Operations and Maintenance activities

5.2.1 BASELINE VERIFICATION: Software baseline documents shall be reviewed at the control point to confirm they are complete and indicate the activity under review was performed in conformance with the criteria specified for each phase in the Software Life Cycle. The review shall be conducted according to QMP-3.07. Routing and approval of baseline verifications (and reviews) are documented on the SCM form. The reviewer shall be independent of the development or modification of the software to be reviewed. The person who directed the work may perform the review with a higher level of management approval and documented justification. The review shall document the extent to which the results of Life Cycle activities agree with the specified acceptance criteria as listed for each software baseline document. The Team Chiefs shall approve the software baseline documents following resolution of review comments. Approval is documented on the SCM form (Attachment 2 or equivalent). A copy of the updated form is submitted to the Chief, EAG, for tracking purposes.

5.2.2 SOFTWARE PHASES AND DOCUMENTATION: Documentation of life cycle phases shall be adequate to allow for an independent repetition of the use of the software and to demonstrate the ability of the software to meet the requirements of this QMP.

5.2.2.1 Requirements Specification and Validation Plan. This phase provides a description of the overall nature and purpose of the software. A plan for performing software validation is provided. The requirements for the intended use of software shall be identified with enough information to frame the problem and characterize (1) functionality criteria, (2) design constraints, and (3) attributes. Testing shall be the primary method used for validation. The Validation Plan shall list each test to be run, and any test procedures needed to perform the test. For each test to be performed, acceptance criteria shall be specified. Validation of modifications to previously released software shall, at a minimum, include regression testing to ensure the integrity of the original requirements.

5.2.2.1.1 Baseline Document Verification: Review and approval of the Requirements Specification and Validation Plan shall ensure the software selected is applicable to the problem being solved, and that the Requirements Specification document is complete. Furthermore, the Validation Plan review shall ensure the plan will adequately test the software against the functional requirements.

5.2.2.2 Design Description and User Documentation: This phase consists of software design and source code development, and software user documentation. The Design Description document shall describe the performance requirements of the

software, and include descriptions of any numerical approximations. A description of each utilized software item as it relates to the requirements specification (Section 5.2.2.1) shall be included. The document also shall include a description of the structure including internal interfaces, control logic, and data structure and flow. It shall address operational issues such as the name(s) and version of programming language(s), portability, maintainability, reliability, and efficiency Interfaces with external data, hardware or software, if any, shall be described. Software user documentation shall include basic information such as installation procedures, hardware and software operating environments, input and output options, file formats, default parameters, data files, and input and output files. Any available sample problems or data sets shall be described as well as anticipated errors and remedial actions The allowable and tolerable ranges of inputs and outputs, if applicable, shall be specified. A copy of the executable and source code will be provided.

> 5.2.2.2.1 Baseline Document Verification: Review and approval of the design description shall verify that the design performance requirements are met and the description document is complete. Review and approval of the user documentation shall ensure that the documentation is complete.

5.2.2.3 Software Validation Report: This phase consists of validation testing. The Validation Report shall include the results of the software validation tests described in the Validation Plan to ensure the software functions for the use(s) described in the Requirements Specification. The report also shall describe the extent to which the test results agree with the acceptance criteria described in the Validation Plan.

> 5.2.2.3.1 Baseline Document Verification: Review and approval of the Software Validation Report shall confirm that the software validation test results ensure the software is adequate for the intended use.

5.2.2.4 Software Release: When all required documents have been approved by the appropriate Team Chief, the Chief, EAG, shall verify that all QMP requirements have been met, sign the SCM form to indicate approval for release of the software, and notify the Technical Contact by returning the signed form. After release of the software the Primary User shall use the software as stated on the Requirements Specification. In those cases where verification and validation cannot be met prior to the release of the software, the portions of software that have not been verified and validated shall be identified and controlled, and written justification of the reason documented.

5.2.2.5 Operation and Maintenance: This phase comprises the use of released software to support YMPB activities. This phase may include software modification, software defect identification and resolution, distribution, and withdrawal or retirement. These actions require documentation in accordance with appropriate elements of Configuration Control, Section 5.6.2 of this QMP.

5.2.2.5.1 Modifications: Approval for modification to released software and/or software baseline documents shall be initiated by providing updated software baseline documents that reflect the change. A description of the change, the rationale for the change, and the identification of affected baseline documents shall be included. An SCM form (Attachment 2 or equivalent) and a new SIF (Attachment 1 or equivalent) shall accompany the updated software baseline document. All of these documents shall follow the original review and approval process (Sections 5, and 5.2). Only approved modifications shall be made to software baselines. Written information concerning modifications shall be transmitted to all documented software users by the Chief, EAG.

5.2.2.5.2 Software Defect Identification and Resolution: A suspected software defect shall be reported on an SCM form (Attachment 2 or equivalent) to be forwarded to the Technical Contact who will determine whether it is a software defect and not a user error. If there is a defect, the Technical Contact shall sign and send the SCM form to the Chief, EAG, for tracking. Identified defects shall be reported to any documented users of the software by the Chief, EAG. A Software Defect Resolution Report shall be prepared by the Technical Contact. This report shall include proposed modifications to the software and/or the software baseline documents and shall address potential impacts of the defect, if any, as a result of previous use of the software. This report shall be reviewed in accordance with QMP-3.07 and shall be approved by the appropriate Team Chief on the SCM form. If a defect is identified in software that adversely impacts previous applications, then the condition adverse to quality shall be documented and controlled in accordance with AP-16.1Q. Upon approval of the Resolution Report, modification to the software baseline documents, if any, shall then be performed in accordance with Section 5.2.2.5.1. The Chief, EAG, shall transmit a copy of the approved Resolution Report to all documented software users.

5.2.2.5.3 Distribution: Released software may be used by other software users within the YMPB. The Principal Investigator for an additional software user shall identify the application of the software on an SCM form (Attachment 2 or equivalent). The signature of a reviewer who is independent of the proposed SCP activity use shall be provided to ensure that the software selected is applicable to the problem to be solved and that the use falls within the range specified in the baseline documentation. The SCM form shall be submitted to the Chief, EAG, for approval and baseline status accounting. The Chief, EAG, shall transmit a copy of the signed form to the Technical Contact.

5.2.2.5.4 Retirement or Withdrawal: Retirement or withdrawal of released software shall be documented by submitting a completed SCM

form (Attachment 2 or equivalent). If a Technical Contact wishes to withdraw or retire software, the Chief, EAG, shall approve the withdrawal/retirement on the SCM form and return a copy of the signed form to the Technical Contact. Information concerning retirements or withdrawals shall be transmitted to all documented software users by the Chief, EAG. If another Principal Investigator or Technical Contact within the YMPB wishes to continue use of the software, the new Principal Investigator will transfer responsibility for the software to the new Technical Contact. The new Technical Contact will submit a new SIF (Attachment 1 or equivalent) to the Software Overview Board.

5.3 Acquired Software: Software acquired from outside the YMPB that can be verified by visual inspection and/or hand calculations shall meet the requirements as defined in Section 5.1. Acquired software that has not been documented following a configuration management system equivalent to that described in Section 5.6 of this QMP will be treated the same as developed or modified software (Section 5.2) with the following exceptions;

1) at least one test in the Validation Plan (Section 5.2.2.1) must be designed independently of the developer;

2) only documentation of (a) interfaces with external data, hardware, or other software and (b) numerical approximations are necessary in the Design Description (Section 5.2.2.2); and

3) executable code that is not proprietary must be submitted as part of the User Documentation. Source code is not required.

5.4 Equivalent Life Cycle Software: For software acquired from an Affected Organization, or for commercial-grade or proprietary software, a Primary User may employ software and associated baseline element documentation provided the software and associated elements are developed in accordance with a life cycle plan which incorporates a Quality Assurance program equivalent to this QMP or the Department of Energy (DOE) QARD Supplement I. As with documentation for other levels of software, the Principal Investigator for the YMPB Primary User assigns a Technical Contact.

For software acquired from an Affected Organization, the Technical Contact shall obtain copies of the software and associated Life Cycle baseline element documentation, or a reference to the Yucca Mountain records accession number.

For commercial-grade or proprietary software, the software provider shall submit necessary information to the Chief, EAG, to determine the provider's software life cycle plan is equivalent to the life cycle plan described in this QMP or the DOE's QARD Supplement I.

The Technical Contact must submit an SIF, an SCM form (Attachment 1 and 2 or equivalent(s)), and a Requirements Specification. The Primary User shall list their Require-

ments Specification and the equivalent life cycle software documentation provided by the software source on the SCM form. The Primary User must also indicate the software is used within the bounds specified in the baseline documentation available from the software provider. The Requirements Specification shall meet the criteria described in para. 5.2.2.1, and shall be reviewed according to para. 5.2.1. and para. 5.2.2.1.1.

Baseline verification by the YMP-USGS Primary User is not required for life cycle documentation from a commercial-grade, proprietary, or Affected Organization software provider. Notwithstanding, Team Chief approval shall be documented on the SCM form. Release (Section 5.2.2.4) and Operation and Maintenance (Section 5.2.2.5) activities shall follow the procedures of this QMP.

5.5 Software Overview Board: The Software Overview Board is responsible for determining the necessary documentation for software that falls under the scope of this QMP. The Software Overview Board shall consist of a Chair (the Chief, EAG, or delegate) and two representatives selected by the Chief, ESIP. The Board will meet on an ad-hoc basis or monthly as deemed appropriate by the Chair. The Software Overview Board Chair arranges for the Board to review SIF's submitted by Technical Contacts. The Board will determine whether the software requires documentation under Section(s) 5.1, 5.2, 5.3, or 5.4 of this QMP. The Chair documents the Board's decision on the SIF, returns the approved SIF to the Technical Contact, and retains a copy in the EAG files.

5.6 Software Configuration Management: Software configuration management includes configuration identification, configuration control, and status accounting for software baselines.

5.6.1 CONFIGURATION IDENTIFICATION: Configuration identification shall include a definition of baseline elements of each software baseline. Each version of software and revision of associated software items under software configuration management shall have a unique identification number to serve as a reference between software items, baselines, and software output.

5.6.2 CONFIGURATION CONTROL: The release and control process for baseline elements is governed by the procedures outlined in this QMP. For each baseline element, upon approval by the appropriate Team Chief, an updated copy of the SCM form (Attachment 2 or equivalent) is forwarded to the Chief, EAG, for status accounting. Once all baseline elements have been approved, software is released in accordance with Section 5.2.2.4. The Chief, EAG, shall forward a signed SCM form to the YMPB Technical Contact identified on the SCM form. The Principal Investigator is responsible for submitting completed records to the Project records facility in accordance with QMP-17.01, or its successor DOE AP-17.1Q.

5.6.3. STATUS ACCOUNTING: The Chief, EAG, shall maintain a status accounting system. The system shall include a listing of the approved software baseline elements and unique identifiers, the status of proposed changes to the

baseline elements, and a brief chronology of the software items, including descriptions of the changes made between versions of software items.

6. RECORDS MANAGEMENT.

6.1 CONTROLLED DOCUMENTS: None.

6.2 RECORDS CENTER DOCUMENTS: Records associated with this procedure shall be submitted as lifetime records (QA: L) through the YMPB Records Coordinator to the Project records facility by the Principal Investigator in accordance with QMP-17.01 (or successor procedure AP-17.1Q). Records/record packages include any of the QMP Attachments or equivalents, along with a variety of exhibits and notifications.

7. RELATED DOCUMENTS.

7.1 SUPERSEDED DOCUMENTS: This QMP supersedes YMP-USGS-QMP-3.03, R6, Software, and Modifications M1 and M2.

7.2 REFERENCES CITED:

- YMP-USGS-QMP-3.04, Review and Approval of YMP-USGS Data, Interpretations of Data, and Manuscripts
- YMP-USGS-QMP-3.07, YMP-USGS Review Procedure
- YMP-USGS-QMP-3.16, Scientific Expert Elicitation
- YMP-USGS-QMP-5.01, Preparation of Technical Procedures
- YMP-USGS-QMP-5.05, Scientific Notebook
- YMP-USGS-QMP-12.01, Instrument Calibration
- YMP-USGS-QMP-17.01, YMP-USGS Records Management
- DOE AP-16.1Q, Performance Deficiency Reporting
- DOE AP-17.1Q, Record Source Responsibilities for Inclusionary Record
- Quality Assurance Requirements and Description, QARD Supplement I DOE/RW-0333P

8. ATTACHMENTS.

Attachment 1: Software Identification Form
Attachment 2: Software Configuration Management Form

9. HISTORY OF CHANGES.

Revision/ Modification No.	Effective Date	Description of Changes
R0	10/27/86	Initial Issue.
R1	07/28/89	To implement the requirements of YMP-USGS-

		SQAP-01, R0.
R1-M1	08/24/89	To clarify exemptions associated with Standard Procedure Software.
R2	06/04/90	To clarify and simplify requirements as a result of the implementation learning curve.
R2-M1	02/01/91	To adjust the time frame requirements for Software Technical/Peer Reviews.
R2-M2	08/16/91	To simplify Attachments 2 and 3.
R3	02/03/92	To clarify language in QMP-3.03, R2, as agreed upon in comment resolution meeting 04/30/90, to implement preventative actions as a result of USGS-CAR-91-09 and DOE CARs YM-91-074, -075, -076, and -077; and to provide consistency with changing YMP requirements for software. Incorporated requirements of QMP-3.14.
R3-M1	03/12/92	To provide for documentation of independent verification on Attachments 3, 4, and 5.
R3-M2	11/09/92	To provide direction in the application of requirements regarding "nature, complexity, and importance" per recommendation of DOE Audit YM-93-01.
R3-M3	03/05/93	To clarify the requirements for conditional release of software and to update the definition of and requirements related to "Software Product" per USGS-NCR-93-04.
R3-M4	07/22/93	To provide consistency with DOE/RW-0333P (QARD, R0) and to resolve outstanding comments to QMP-3.03, R3-M3.
R-4	10/15/93	To provide consistency with DOE/RW-0333P (QARD, R0 in accordance with the USGS QARD Transition Plan.
R4-M1	04/22/94	Changed to address QARD requirements for Supplement I and in response to concerns identified during YMQAD Surveillance No. YMP-SR-94-

		039 (CAR YM-94-027 was not addressed in this Modification).
R4-M2	06/10/94	Changed to provide for documentation of independent review of software applications resulting from software transfers. This change originated as preventative action under DOE CAR YM-94-027.
R4-M3	07/14/94	No description.
R5	10/31/94	Incorporates Modification QMP-3.03, R4-M1 and changes procedure to allow identification executable copies of acquired software in response to concerns identified during YMQAD Audit 94-06.
R6	07/15/96	Changed to address DOE QARD Revision 2 Supplement I requirements.
R6-M1	07/15/96	Incorporates editorial changes to pages 3, 4, 10, page 1 and 2 of Attachment 1, and page 1 of Attachment 2.
R6-M2	10/28/96	Changed Scope of Compliance statement to exempt software used in expert elicitation from this QMP. Added reference YMP-USGS QMP-3.16, Scientific Elicitation.
R7		Revised to reflect transition from USGS QA to USGS EAG and DOE/OCRWM OQA functions and responsibilities.

10. APPROVALS AND EFFECTIVE DATE.

EFFECTIVE DATE: June 2, 1997

APPROVALS:

YMP-USGS Quality Assurance Manager	4/30/97 Date
Chief, Yucca Mountain Project Branch	4/30/97 Date
Assistant Chief Hydrologist for Technical Support	5/2/97 Date
Senior Advisor for Science Applications	5/2/97 Date

CONCURRENCE:

DOE/OCRWM, Office of Quality Assurance Representative	5-8-97 Date

SOFTWARE IDENTIFICATION FORM

Software Identification Assignment

(Leave blank if not yet assigned or if not required.)

Instructions: Use this form to request an identification number for software or a new version of software.

Purpose *(Check one.)*

☐ Initial identification of software or software version.

☐ Change to previously submitted information for software.

Software Information

Software Name: _____

Software Version/Release: _____

☐ This software is a revision of previously released software. On attached sheets describe modification, rationale for the modification, affected software baseline documents, and identify supporting software baseline documents that remain in effect.

Technical Contact

Name: _____

Address: _____

Phone Number: _____

E-Mail: _____

YMPB Activity (Primary User)

SCP Activity Number: _____

Title: _____

Principal Investigator

Name: _____

Address: _____

Phone Number: _____ E-Mail: _____

Signature: _____ Date _____

SOFTWARE IDENTIFICATION FORM

Software Overview Board Decision:

☐ Exempt ☐ Limited Requirement ☐ Full Life Cycle

☐ Acquired Outside YMPB ☐ Equivalent Life Cycle Software

_____ _____

Software Overview Board Chair Date

Limited Requirement Software:

Document submittal under QMP ☐ 3.03 ☐ 3.04 ☐ 5.01 ☐ 5.05

Source (Check one)

☐ This software was acquired as Equivalent YMPB Life Cycle Software.

☐ This software was developed specifically for activities.

☐ This software was acquired externally from the YMPB.

For acquired and equivalent life cycle software provide the following:

Provider Name: _____

Address: _____

_____

SOFTWARE CONFIGURATION MANAGEMENT FORM

Instructions: Use this form as a cover sheet to identify documents submitted in support of software. It also may be used to report defects or to withdraw or retire previously released software.

Software Identification

Software Name: _____

Software Version/Release: _____

Purpose

- ☐ Document routing and approval *(see below)*.
- ☐ Defect report *(see page 2)*.
- ☐ Distribution *(of released software, see page 2)*.
- ☐ Withdraw/retire the identified software:Chief, EAG Approval _____
  Chief, EAG, YMPB Date
- ☐ Acquisition of Equivalent Life Cycle Software Documentation *(see page 2)*

Document Routing and Approval:

	Submitted by:	Date	Team Chief	Date
Requirements Specification				
Review				
Validation Plan				
Review				
Design Description				
Review				
Software User Document				
Review				
Software Validation Report				
Review				

Approval for Release _____
Chief, EAG Date

SOFTWARE CONFIGURATION MANAGEMENT FORM
(Continued)

Software Defect Report

On an attachment describe and document as completely as possible any suspected defects in the identified software. Forward directly to the Technical Contact for concurrence.

Team Chief _____ Date _____ Technical Contact _____ Date _____

☐ Distribution of Released Software ☐ Acquisition of Equivalent Life Cyle Software Documentation

Identify the additional YMPB activity that will be using the released software. The use of the software by this activity must be encompassed within its use by the primary user.

SCP Activity Number: _____

Title: _____

Identify Application: _____

My review ensures that the software selected is applicable to the problem to be solved and that use is within the ranges in the baseline documents.

Independent Reviewer _____ Date _____

Originator

☐ Technical Contact for identified software

☐ Principal Investigator for above-named activity

☐ Other

Name: _____

Address: _____

Phone Number: _____ E-Mail: _____

Signature: _____ Date: _____

Send this form to: Chief, Engineering Assurance Group, Yucca Mountain Project Branch
U.S. Geological Survey, Box 25046, MS-425
Denver, CO 80225-0046.

ENCLOSURE

#4

Office of Civilian Radioactive Waste Management QA: QA

DOC.20030902.0003

PROCEDURE

SOFTWARE MANAGEMENT

AP-SI.1Q

Revision 5 ICN 2

Effective Date: 09/02/2003

Preparer: F.B. Platko Date 8/28/03

Approval: N. H. Williams Date 8/28/03
Manager, Repository Design

CHANGE HISTORY

Revision Number	Interim Change No.	Effective Date	Description of Change
0	0	02/15/1999	Initial issue to consolidate software configuration management control within the Office of Civilian Radioactive Waste Management program and to create a centralized software library for software that is subject to the Quality Assurance Requirements and Description, DOE/RW-0333P. These items were identified as recommendations in Corrective Action Request LVMO98-C-006. This document replaces QAP-SI-3, Software Configuration Management; LANLYMP-03.20, Software Configuration Management; YMP-LBNL- QIP-SI.1, Software Configuration Management; portions of 033-YMP-QP 3.2, Software Quality Assurance; portions of QAIP 19.1, Software Quality Assurance Requirements; and portions of YMP-USGS-QMP-3.03, Software.
1	0	05/05/1999	Major revision to add a standardized software life cycle development process for Office of Civilian Radioactive Waste Management software development activities controlled by the requirements of the Quality Assurance Requirements and Description, DOE/RW-0333P. To reflect this additional scope, the title of the procedure is being changed from Software Configuration Management to Software Management. This revision also addresses a consistent software planning process in preparation for the software life cycle. This procedure revision supersedes the following procedures that currently control Office of Civilian Radioactive Waste Management specific quality-affecting software life cycle management: QAP-SI-0, Computer Software Qualification; LANLYMP-QP-03.21, Software Life Cycle; YMP-LBNL-QIP-SI.0, Computer Software Qualification; 033-YMP-QP 3.2, Software Quality Assurance; QAIP 19-1, Software Quality Assurance Requirements; and YMP-USGS-QMP-3.03, Software.

CHANGE HISTORY (Continued)

Revision Number	Interim Change No.	Effective Date	Description of Change
2	0	10/15/1999	Complete revision to integrate the Software Management Process with the new suite of procedures developed out of the Process Validation and Reengineering activity. Section added to address how to handle discovery of software previously used on the program whose history is unknown or of indeterminate pedigree. A new process for handling software routines and macros has been added. Single user software steps added to track user information for software where the developer will be the only user (a condition for closure of Deficiency Report LVMO-98-D-030). A new independent verification process has been implemented to replace the QAP 6.2, Document Review, review process. References have been updated.
2	1	10/29/1999	This ICN changes Section 5.11 allowing for the use of an impact evaluation for discovered software that was acquired/developed under previous quality procedures and will be baselined and retired from use.
2	2	12/15/1999	This ICN deletes all references to AP-3.15Q. The internal referencing within this procedure of software defining life cycle documentation was never intended to fall under AP-3.15Q. AP-3.15Q is concerned with making links between technical products and inputs to those products so that if the inputs change the resulting "where used" documents can be identified. The ICN also reflects the ownership change from the Office of Project Execution to Office of Information Management.

CHANGE HISTORY (Continued)

Revision Number	Interim Change No.	Effective Date	Description of Change
2	3	02/07/2000	This ICN incorporates all changes to bring AP-SI.1Q into compliance with QARD, Rev 9 changes. The ICN also provides an additional section covering software operational considerations, Software use, editorial changes to provide clarification and readability and assigns responsibility to the software CM organization for compilation and submission of all appropriate records associated with software management. Control Point 1 and 2 reviews will be accomplished by Information Technology staff effective with this ICN.
2	4	02/22/2000	This ICN inserts editorial changes not inserted in the final version of Rev 2, ICN 3.
3	0	04/01/2001	Complete revision to incorporate an adaptive Software Life Cycle Methodology, including a Software Activity Evaluation and Categorization process, and adding applicable aspects of the Software Engineering Institute Capability Maturity Model (CMM). Incorporates Rev 2, ICN 4, ECN 1 to this procedure.
3	1	05/09/2001	ICN to reformat the Software Categorization Checklist as an Automated Forms System form.
3	1, ECN 1	06/28/2001	ECN 1 issued to extend the date in Subsection 5.10 to six months after the Site Recommendation submission to the President.
3	2	10/25/2001	Procedure revised to incorporate ECN 1 changes to Subsection 5.10 and accepted Document Action Requests D796, D807, D870, D881, D898, D947, and D1030.
3	2, ECN 1	10/25/2001	ECN 1 issued to change Paragraph 2.1.4 back to Revision 3, ICN 1, ECN 1 terminology.

CHANGE HISTORY (Continued)

Revision Number	Interim Change No.	Effective Date	Description of Change
3	3	12/21/2001	ICN incorporates ECN 1 changes to Paragraph 2.1.4 and reflects the ownership and accountability change from the Office of Civilian Radioactive Waste Management Chief Information Officer to Bechtel SAIC Company, LLC Chief Information Officer.
3	4	05/17/2002	ICN clarifies process to follow when a user's operating system is upgraded (Sections 5.7 and 5.8, and Attachment 8), in response to DAR-D3063. All notes in the procedure have been removed to support closure of YMSCO-01-D-064.
4	0	01/13/2003	Complete revision to address issues raised by BSC-01-C-002 and Management Improvement Initiative regarding the addition of supplemental procedures for software management. Also includes software categorization process changes and the addition of software independent verification and validation.
5	0	04/23/2003	Complete revision to address consolidation of Level A software activities into AP-SI.2Q, *Qualification of Level A Software*; rework process flows to address organizational hand-off issues, role responsibilities, and provide clearer definition of work products and forms; remove most uses of AP-2.14Q, *Review of Technical Products and Data*, for IV&V comment resolution activities; and address the following Document Action Requests: D7127, D6447, D6449, D6451, D6452, D6487, D6488, D6490, D6508, D6509, D6510, D6511, D6512, D6513, D6927, and D6970.
5	1	07/08/2003	ICN to address Document Action Request D8748.
5	2	09/02/2003	ICN to address Document Action Request D10433.

1.0 PURPOSE

This procedure, with AP-SI.2Q, *Qualification of Level A Software,* and AP-SI.3Q, *Software Independent Verification and Validation,* establishes the processes, identifies the roles, and defines the responsibilities for management of software to be used in support of quality-affecting activities. The processes include the use of existing qualified software, software categorization and planning, qualification of acquired and developed software, independent verification and validation (IV&V), operations and maintenance, baseline change control, software problem reporting and resolution, and continuous operation software. This procedure provides for a centralized control of quality-affecting software and qualification documentation that is subject to the *Quality Assurance Requirements and Description* (QARD), DOE/RW-0333P, and, as such, in conjunction with AP-SI.2Q and AP-SI.3Q, shall be the Software Quality Assurance Plan for software management.

Supplemental internal organizational controls are allowed and encouraged under this procedure.

2.0 APPLICABILITY

This procedure applies to software that is subject to the QARD; individuals within Bechtel SAIC Company, LLC; the National Laboratories; the U.S. Geological Survey; Bechtel SAIC Company, LLC contractors; and other contractors who acquire, develop, control, or manage software, or who use software in the Office of Civilian Radioactive Waste Management (OCRWM) Program.

Applications developed using non-standard functions in commercial off-the-shelf software (see Subsection 3.6) and that are directly used for quality-affecting work shall be qualified in accordance with this procedure.

Qualified software in the centralized baseline, as of the effective date of this procedure, shall be considered acceptable and part of the established baseline until the software is changed.

In-process software development activities that have not reached a Control Point review on the effective date of this procedure shall transition to meet the requirements of this procedure. Software that is in or past a Control Point review upon the date that this revision becomes effective may complete the review process in accordance with the previous revision of this procedure.

2.1 SOFTWARE NOT REQUIRED TO BE QUALIFIED UNDER THIS PROCEDURE

The following types of support software, when used for quality-affecting work, are considered to be controlled under the Software Configuration Management (SCM) system, but are not required to be qualified or documented under this procedure, except as noted:

2.1.1 Software such as operating systems, system utilities, compilers and their associated libraries, word processors, spreadsheets, database managers, e-mail, and other types of automated office support systems.

2.1.2 Software used solely for visual display or graphical representation of data used in a technical product, or that controls data acquisition equipment but does not perform a calculation or obtain a solution, that is checked and approved in accordance with applicable procedures, and meets stated acceptance criteria.

2.1.3 Computer aided design systems generating design drawings that are checked and approved in accordance with AP-3.24Q, *Drawings*.

2.1.4 Acquired software that is embedded in the equipment or integral to the operations, maintenance, or calibration of measuring and test equipment, and that has not been developed or modified, and is tested and controlled in accordance with AP-12.1Q, *Control of Measuring and Test Equipment and Calibration Standards*.

2.1.5 Software used in scoping and bounding determinations, feasibility studies, prototype methodology development, or similar activities prior to actual use in quality-affecting activities. Prior to actual use in quality-affecting activities, such software shall be qualified in accordance with this procedure. Technical products developed using this type of software cannot be issued or checked until the software has been qualified, issued by SCM, final runs made using the qualified software.

2.1.6 Solutions to a calculation or analysis package used to support a technical product (as defined in Subsection 3.37), written using the standard functions of commercial off-the-shelf software programs (e.g., EXCEL, MATHCAD). The results shall not be dependent on the software program used (e.g., the same result could be obtained whether Excel or another spreadsheet was used). The solution must be documented in sufficient detail in a technical product to allow an independent reviewer to reproduce or verify the results by visual inspection or hand calculation without recourse to the originator.

2.2 SOFTWARE REQUIRED TO BE QUALIFIED UNDER THIS PROCEDURE

All other software used for quality-affecting activities shall be qualified and documented in accordance with this procedure.

3.0 DEFINITIONS

3.1 ***Acquired Software***–Software that was neither developed nor modified by an OCRWM-affected organization, and was obtained from a source outside OCRWM.

3.2 ***Affected Organizations***–An organization performing Program work subject to QARD requirements whose organizational relationships are defined in OCRWM Program documents. (QARD)

3.3 ***Application* (Software)**–1) Software designed to fulfill the specific needs of a user. 2) Software that are written where the user prescribes one or more instructions to generate data, manipulate data, or perform calculations. (QARD)

3.4 ***Baselined Software***–An individual software component (e.g., requirements document [RD], design document, source code, etc.) that is under configuration management control. (QARD)

3.5 ***Baselined Software Changes***–Alterations made to software that is under SCM control.

3.6 ***Commercial Off-The-Shelf Software***–Software that a person can buy, ready-made, from some supplier's/retailer's store shelf or manufacturer's virtual store shelf (e.g., through a catalog or from a price list) on the basis of specifications set forth in the manufacturer's published product description (e.g., a catalog or other published specification).

3.7 ***Control Point***–A point at which the products of a series of life cycle phases are fixed and controlled.

3.8 ***Developed Software***–Software that is developed or acquired and that has been modified by an organization, as identified in Section 2.0 of this procedure.

3.9 ***Developer***–An individual who writes software.

3.10 ***Developing Organization***–An organization developing software subject to this procedure.

3.11 ***Editorial Corrections***–Modifications made to a document such as correcting grammar, spelling, or typographical errors; renumbering sections or attachments (as long as the renumbering does not affect the chronological sequence of the work); modifying the title or number of the document; or updating organizational titles (as long as responsibilities are not changed).

3.12 ***Embedded Software***–1) The software associated with firmware that can provide function and control capabilities. 2) Software that is a fixed part of a larger system and performs some of the requirements of that system.

3.13 ***Firmware***–Software (program or data) that has been written onto read-only memory.

3.14 ***Independent Verification and Validation (IV&V)***– The office, position, or organization assigned responsibility for the software verification and validation processes that fall under the scope of this procedure. The IV&V performs systematic evaluation of software

products and activities, and is not responsible for developing the product or performing the activity being evaluated.

3.15 ***In-Process Change***–Change made during the life cycle process, but prior to the software being baselined.

3.16 ***Modified Software***–Baselined software that is being changed (i.e., modifications to previously baselined developed software, or modifications made by OCRWM to previously baselined acquired software).

3.17 ***Notification***–For the purpose of this procedure, *notification* is an information-only activity and does not require documented evidence of compellation.

3.18 ***Operating Environment***–The operating environment includes a collection of software, firmware, and hardware elements that provide for the execution of the software.

3.19 ***Operating System***–A collection of software that controls the execution of computer programs and provides such services as computer resource allocation, job control, input/output, and file management in a complete system.

3.20 ***Qualified Software***–Software that is acquired, developed, or modified, and successfully baselined and released by SCM.

3.21 ***Range of Validation***–The documented type(s) of functionality and range of input for which the software is qualified to be used.

3.22 ***Regression Testing***–Selective retesting of a system or component to verify that modifications have not caused unintended effects, and that the system or component still complies with its specified requirements. (QARD)

3.23 ***Responsible Manager (RM)***–The manager with line responsibility for performance of the activity that the software items will support.

3.24 ***Software***–Computer programs, procedures, rules, and associated documentation pertaining to the operation of a computer system. (QARD)

3.25 ***Software Configuration Management (SCM)***–The office, position, or organization assigned responsibility for the control of software that falls under the scope of this procedure.

3.26 ***Software Coordinator***–1) A person who is the point of contact that coordinates software items and issues and/or, 2) A technically qualified person who should be independent of the software development activity and not part of the IV&V, and who conducts and documents verifications prior to submission for IV&V.

3.27 ***Software Item***–Source code, object code, job control code, control data, or a collection of these items that function as a single unit. (QARD) For purposes of this procedure, software

items also include the procedures, rules, associated documentation, and information pertaining to the operation of a computer system.

3.28 ***Software Life Cycle***–A series of activities that begins when the software product is conceived and ends when the software product is no longer available for routine use. A defined software life cycle methodology shall address the following phases: requirements, design, implementation, testing, installation and checkout, operations and maintenance, and retirement. The number of phases and relative emphasis placed on each phase of the software life cycle will depend on the nature and complexity of the software. Software life cycle activities may be performed in an iterative or sequential manner. (QARD)

3.29 ***Software Media***–A device and/or entity (magnetic tape, diskette, CD-ROM, etc.) on which a software item is stored. Media shall be prepared using work activities/processes/process functions evaluated in accordance with AP-SV.1Q, *Control of the Electronic Management of Information.*

3.30 ***Software Problem***–Any failure of a software document, code, data structure, or process to meet its requirements or standards.

3.31 ***Software User***–The person(s) who operates or interacts directly with the system or software.

3.32 ***Software Validation***–The test and evaluation of completed software to ensure compliance with software requirements. (QARD)

3.33 ***Software Verification***–The process of determining whether or not the product(s) of a given phase of the software development cycle fulfills the requirements imposed by the previous phase. (QARD) An example of software verification is the comparison of the proposed design against the documented requirements to ensure that all requirements are addressed in the design.

3.34 ***Status Accounting***–a) Management of a centralized software baseline containing unique software identifiers, chronology of software, and a description of the changes made between versions of software. b) Communication of software baseline status, including proposed, in-process, or approved software.

3.35 ***Target Platform***–The computer(s) on which the software is intended to be used.

3.36 ***Technical Installer***–The individual installing the software on a User's computer in preparation for software use (normally as a result of Attachment 1, Software User Request, being submitted).

3.37 ***Technical Product***–Any product containing engineering or scientific information with relevance to the characterization, licensing, design, and/or operations of the Civilian Radioactive Waste Management System. For the purpose of this procedure, this definition includes analyses (in accordance with AP-SIII.9Q, *Scientific Analyses*), model reports (in accordance with AP-SIII.10Q, *Models*), reports (in accordance with AP-3.11Q, *Technical Reports*), engineering calculations (in accordance with AP-3.12Q, *Design Calculations and*

Analyses), and specifications (in accordance with AP-3.19Q, *Specifications*), or other technical documents that are subjected to a review process.

4.0 RESPONSIBILITIES

4.1 The Manager of Repository Design is responsible for the preparation, change, and approval of this procedure

4.2 The following roles are responsible for activities identified in Section 5.0 of this procedure (individuals may perform one or more of these roles):

a) Software User
b) Software Coordinator
c) SCM
d) Technical Installer
e) RM
f) Developer
g) IV&V

5.0 PROCESS

Software items subject to QARD requirements cannot be used in quality-affecting activities prior to the software being baselined and qualified. The QARD-defined software life cycle methodology addresses the following phases: requirements, design, implementation, testing, installation and checkout, operations and maintenance, and retirement.

A Software User initiates this process by identifying a need or general requirement. The Software User then checks to see if qualified software on the baseline is available to meet the identified need. If qualified baseline software is available, use Subsection 5.1.

If qualified baseline software is not available, obtain the category of the software in accordance with Subsection 5.2 and proceed through the process based on the determined level of software categorization. The RM/Developer should determine if software could be acquired to meet the desired need.

Required independent software verification and software validation is performed using AP-SI.3Q.

The OCRWM-provided SCM tool should be used, where available, in conjunction with this process.

A functional process flow of this process is depicted in Attachment 2, AP-SI.1Q Flowchart. Acronyms and abbreviations used in this procedure are defined in Attachment 3, Acronyms and Abbreviations, and/or in the flowchart legend.

PROCESS OUTLINE

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5.1 USE OF QUALIFIED SOFTWARE

5.1.1 Requesting Qualified Software

5.1.1.1 Software User:

a) Locate desired software on the *Baseline of Qualified Software Report* and confirm that the software is qualified for the operating environment and validation range required.

b) If the software is not qualified for the required operating environment, proceed to Paragraph 5.8.2.

c) If the software has not been qualified for the targeted validation range, proceed to Paragraph 5.8.3.

d) If the software is not on the *Baseline of Qualified Software Report*, proceed to Subsection 5.2.

e) Prepare Attachment 1, Software User Request, completing the Software User/Developer actions in accordance with the form instructions.

f) Submit the Software User Request (SUR) to the Software Coordinator.

5.1.1.2 Software Coordinator:

Submit the SUR to SCM to request distribution of or access to a baselined software item.

5.1.1.3 SCM:

a) Update Status Accounting.

b) Update the SCM actions on the SUR in accordance with the form instructions.

c) Provide the installation package for the requested software (installation package includes the software package, installation instructions, and SCM checklist), along with the SUR, to the Software Coordinator.

5.1.1.4 Software Coordinator:

Provide the installation package and SUR received from SCM to the Technical Installer.

5.1.1.5 Technical Installer:

a) Install the software on the target platform in accordance with the installation package.

b) Confirm proper software installation and readiness for operational use.

c) Update the Technical Installer actions on the SUR in accordance with the form instructions.

d) If installation failures occur, use the Software Problem Reporting and Resolution process in Subsection 5.10.

e) Return the installation package and SUR with supporting documentation providing evidence of the installation to the Software Coordinator.

5.1.1.6 Software Coordinator:

a) Notify the Software User that the software is installed, and ensure that the Software User has access to the appropriate documentation to use the software as determined by the Software User.

b) Return the installation package, and the SUR with supporting documentation to SCM.

5.1.1.7 SCM:

a) Update Status Accounting.

b) Submit the completed SUR and supporting documentation to the Records Processing Center (RPC) in accordance with Section 6.0 of this procedure.

5.1.2 Use of Qualified Software

5.1.2.1 RM:

Ensure that all qualified software being used was obtained from SCM.

5.1.2.2 Software User:

Control and document the use of qualified software so that comparable results can be obtained (with any differences explained) through independent replication of the activity or process within the range of validation to which the software was originally qualified. To accomplish this, the documentation must record, at a minimum, the use of the software within the Technical Product or activity output documentation.

5.2 SOFTWARE CATEGORIZATION AND PLANNING

The software management life cycle requires that a software quality assurance plan be in place for each software project, which includes the development, acquisition, or modification of software. The planning requirements for software quality assurance are incorporated into this procedure by the process described for each software product. AP-SI.2Q, for the required documentation for Level A software; and AP-SI.3Q for IV&V reviews. The procedure's use of standard and tailored software life cycle methodologies provides a planned, traceable, and orderly process for software acquisition, development/modification, operations, and maintenance.

For qualification of Level A developed software, the four software life cycle phases are Requirements, Design, Implementation, and Testing. Independent verification of software is conducted:

- At the conclusion of the Requirements Phase (on the RD) by the Software Coordinator
- During the Design Phase (on the design document) by the Software Coordinator
- At Control Point A at the conclusion of the Design Phase (on the Requirements, Design, and Validation Test Process [VTP] documents) by IV&V

- At Control Point B for the Implementation and Testing Phases (on the Installation Test Process [ITP] and User Manual documents, software media, and any modified Control Point A documents) by IV&V.

Checkpoints at Control Point A and Control Point B include independent validation reviews, and the software is baselined by SCM.

For qualification of Level A acquired software, the two software life cycle phases are Requirements and Testing. Independent verification of software is conducted:

- At the conclusion of the Requirements Phase (on the RD) by the Software Coordinator

- At Control Point B for the Testing Phase (on the Requirements, VTP [if the VTP is required], ITP, User Manual documents, and software media) by IV&V.

A checkpoint at Control Point B includes an independent validation review, and the software is baselined by SCM.

For qualification of Level B software, there is a single consolidated software life cycle phase. This consolidated phase consists of elements of the Requirements, Design, Implementation, and Testing phases. The Software Management Report (SMR) combines the Requirements, Design, VTP, and ITP documents. Independent verification for this consolidated phase is conducted prior to Control Point B by the Software Coordinator. A checkpoint at Control Point B includes an IV&V review, and the software is baselined by SCM.

The RM shall categorize software in order to determine the appropriate level of required controls, validation, and verification, based on the nature, function, and complexity of the software. Use Paragraph 5.2.1 to identify the category of quality-affecting software as one of the following:

- Level A
- Level B.

Level A is used to describe software that requires a high level of confidence through validation and verification, based on its nature, function, and complexity (e.g., software that is the numerical implementation of a model; mathematical algorithms that may use complex numerical methods, approximations, or simulations. Level A software is qualified using AP-SI.2Q, and is subject to AP-SI.3Q for IV&V.

Level B is used to describe all other non-Level A software subject to qualification under this procedure that requires a level of validation and verification, based upon its nature, function, and complexity (e.g., software that is used to acquire, manipulate, or transform data, or perform calculations using mathematical algorithms that give exact results). Except for data acquisition software, Level B Software gives identical results when re-run. Level B software is qualified using Subsection 5.3 and is subject to AP-SI.3Q for IV&V.

5.2.1 Software Categorization Evaluation for Software not on the *Baseline of Qualified Software Report*

5.2.1.1 Software User:

Notify the RM that required software is not qualified.

5.2.1.2 RM:

Notify the Developer of the software need.

5.2.1.3 Developer:

a) Initiate page 1 of Attachment 4, Software Configuration Control Request, completing the Developer actions in accordance with the form instructions, including information provided by the RM and Software User.

b) Forward the Software Configuration Control Request (SCCR) to the RM for review, categorization, and approval.

5.2.1.4 RM:

a) Review the SCCR.

b) Resolve issues with the Developer.

c) Assign and approve the appropriate category level on the SCCR by completing the Responsible Manager actions in accordance with the form instructions.

d) Submit the SCCR to the Software Coordinator.

5.2.1.5 Software Coordinator:

a) Request document identifying numbers for software media and documentation using page 2 of the SCCR, completing the Software Coordinator actions in accordance with the form instructions.

b) Submit the SCCR (pages 1 and 2) to SCM.

5.2.1.6 SCM:

a) Assign the Software Tracking Number (STN) and software media and document number(s) on the SCCR, completing the SCM actions in accordance with the form instructions.

b) Update Status Accounting.

c) Provide copies of the SCCR (page 1 and 2) to the Software Coordinator and IV&V.

5.2.1.7 Software Coordinator:

Provide the Developer with the STN and document identifying numbers.

5.2.1.8 Developer:

Software life cycle activities may be performed in an iterative or sequential manner.

a) Use AP-SL.2Q for the qualification of the software if it is categorized as Level A.

b) Use Subsection 5.3 if the software is categorized as Level B.

5.3 QUALIFICATION OF LEVEL B SOFTWARE

Level B developed, or acquired software requires the submittal of an SMR and media, and is validated and verified according to AP-SL.3Q.

5.3.1 Developer:

a) Ensure that the STNs, media numbers, and document identifying numbers are used on required documentation and media throughout the software development activity.

b) Prepare the SMR, using the following outline, to describe the elements addressed and documented. Vendor-supplied documentation may be incorporated by reference provided it complies with AP-IM-002, *Use of Copyright-Protected Materials*. Any referenced vendor-supplied documentation intended for use shall be made available through the Technical Information Center, or through the RPC, as appropriate.

1) Software Identification

- Software name and version number
- The name and version identification of the commercial software under which the software was developed, to the level of detail normally associated with the operating system on which the commercial software resides
- SMR document identification number
- Media number.

2) Description and Testing

- Description of software (e.g., purpose, scope, etc.), including uniquely identified requirements, operating environment, system support/utility software, and any required training necessary to use the software.

- Design description and equations of mathematical models, algorithms, and numerical solution techniques, as they relate to software requirements, as applicable.

- Mapping of design element(s) to requirements, as applicable.

- If the software is to operate in more than one environment (i.e., on multiple platforms or using different operating systems), then this shall be stated in the documentation. Appropriate tests for each platform and/or operating system shall be included.

- Description of the validation test case(s), installation test case(s), including in-use test(s) for continuous operations software (see Subsection 5.11), along with any necessary instructions to execute the test(s) and associated acceptance criteria. Installation testing shall include validation(s) that demonstrate that the software is ready for operational use.

- Instructions adequate for the installation and execution of the software without recourse to the originator or originating organization.

- Mapping of validation test case(s) to requirements.

- Description of test results, including acceptance criteria and validation results, with mapping to test case.

- Range of input and output parameter values for which results were validated.

- Identification of any limitations on applications.

3) Supporting Information (each annotated with software name and version number)

- Directory listing of software files

- Computer listing of source code, if available, and compilation instructions, if applicable

- Computer listing of test data input and output files mapped to test cases.

4) References

Provide a reference list of all documentation relevant to the validation used in the development of the SMR.

c) Clearly identify the software documentation (SMR) as the verification copy (e.g., "verification" or "verification copy") on the document cover sheet and assign the alphanumeric draft designator 00A. Each subsequent revision is assigned an incremented alphanumeric draft designator (e.g. 00B, 00C, etc.).

d) Develop and prepare the software media.

e) Update the SMR if required.

f) Complete page 3 of the SCCR, completing the Developer actions in accordance with the form instructions.

g) Submit page 3 of the SCCR, SMR (verification copy 00A), and media to the Software Coordinator for a verification review.

h) Make no changes, external to the verification review, to the software provided to the Software Coordinator.

5.3.2 Software Coordinator:

Notify the RM if the Software Coordinator is associated with the development of the software and will perform the verification review.

5.3.3 RM:

If the Software Coordinator is associated with the development of the software and will perform the verification review, provide management approval and documented justification to the Software Coordinator.

5.3.4 Software Coordinator:

a) Verify and document the completeness of the SMR in an SMR Verification Report.

b) Coordinate with the Developer to address all comments and re-verify iteratively until all comments have been resolved. Comments and comment resolution shall be documented. E-mail may be used for comments.

c) If a comment cannot be resolved, elevate the dispute to higher levels of management of the Developer and Software Coordinator until resolution is obtained.

d) If the Software Coordinator is associated with the development of the software, attach the management approval and documented justification to the SMR Verification Report.

e) Attach all comment resolution documentation used in this verification review process to the SMR Verification Report.

f) Include on the cover sheet of the SMR Verification Report the words "Verified By:," followed by the Software Coordinator's full name, signature, and date of signature.

g) Ensure that the Control Point B package for Level B software consists of the SMR, software media, page 3 of the SCCR, and the SMR Verification Report.

h) Submit the Control Point B package to IV&V.

i) Make no changes, external to the IV&V review, to the Control Point B package provided to IV&V.

5.3.5 IV&V:

Initiate IV&V for Control Point B for Level B Software in accordance with AP-SI.3Q.

5.3.6 Software Coordinator:

a) Coordinate IV&V comments with the Developer and IV&V to address all comments until all comments have been resolved. E-mail may be used for comments.

b) If a comment cannot be resolved, elevate the dispute to higher levels of management of the Developer and IV&V until resolution is obtained.

c) Notify Developer that comment resolution is complete.

5.3.7 Developer:

a) Upon completion of the IV&V process for this control point, produce the final SMR and remove the alphanumeric designator. The subsequent approval copy is "Rev 00."

b) Include on the cover sheet of the final documentation the words "Verified By:," followed by the full name of the person performing the IV&V.

c) Sign and date the cover sheet of the SMR indicating that the SMR meets the minimum mandatory requirements, and that IV&V has been performed and any comments were resolved.

d) Submit the SMR, software media (if changed), and page 3 of the SCCR (if changed) to the Software Coordinator.

5.3.8 Software Coordinator:

Submit the final Control Point B package to IV&V (SMR; software media, if changed; and SCCR, page 3, if changed).

5.3.9 IV&V:

Complete IV&V for Control Point B for Level B Software in accordance with AP-SI.3Q.

5.3.10 SCM:

Upon receipt of the Control Point B records package:

a) Review the SCCR, as appropriate, verifying that the operating system and version on page 3 of the SCCR are correct.

b) Complete the SCM actions for page 3 of the SCCR in accordance with form instructions.

c) Update Status Accounting.

d) Process the record copies of the software, SCCR, and all Control Point B documentation.

e) Submit the Control Point B records to the RPC in accordance with Section 6.0 of this procedure.

f) Notify the Software Coordinator that Control Point B is complete and provide the Software Coordinator a copy of the SCCR.

5.3.11 Software Coordinator:

Notify the Developer and Software User of the software status.

5.4 CANCELING SOFTWARE

This section applies to the cancellation of software activities after SCM has assigned identification numbers, but before the software has been baselined.

5.4.1 RM:

a) Identify the need to cancel the software activity.

b) Notify or assign the Developer.

5.4.2 Developer:

a) Prepare page 1 of an SCCR completing the Developer actions in accordance with the form instructions.

b) Submit page 1 of the SCCR to RM.

5.4.3 RM:

a) Approve the cancellation by completing the RM actions on page 1 of the SCCR in accordance with the form instructions.

b) Submit the SCCR to the Software Coordinator.

5.4.4 Software Coordinator:

Submit the SCCR to SCM for cancellation.

5.4.5 SCM:

a) Update page 1 of the SCCR by completing the SCM actions in accordance with the form instructions.

b) Update Status Accounting.

c) Submit the SCCR to the RPC in accordance with Section 6.0 of this procedure.

5.5 SCM CONTROL OR RELEASE

SCM:

a) Coordinate any administrative issues regarding baselined software packages with the Software Coordinator or IV&V.

b) Make software available for use after documentation and software media have been completed, reviewed, and approved for release.

c) Update Status Accounting.

d) Submit the completed software records package and individual records to the RPC in accordance with Section 6.0 of this procedure.

5.6 RETIRING SOFTWARE

This section applies to the retirement of qualified software and to software that has completed a control point but will not complete the qualification process. Retired software that had been fully qualified may only be used for the purpose of re-performing the software's previously documented results.

Retirement of software shall be handled as a change to the baseline status of the software and shall be reflected in the SCCR and in Status Accounting maintained within the centralized SCM.

5.6.1 RM:

a) Provide rationale for retirement by completing page 1 of the SCCR in accordance with form instructions for the RM.

b) Request a list of the authorized users of the software from SCM.

5.6.2 SCM:

Provide the list of authorized users to the RM.

5.6.3 RM:

a) Notify authorized users of pending software retirement and obtain concurrence.

b) Authorize the retirement by signing and dating page 1 of the SCCR.

c) Submit the SCCR and user concurrences to the Software Coordinator.

5.6.4 Software Coordinator:

Submit the SCCR and user concurrences to SCM.

5.6.5 SCM:

a) Complete the SCM actions on the SCCR in accordance with the form instructions.

b) Ensure software is not distributed for further use.

c) Notify all authorized users of the disposition of the software.

d) Update Status Accounting.

e) Submit the SCCR and user concurrences to the RPC in accordance with Section 6.0 of this procedure.

5.7 STATUS ACCOUNTING

SCM:

a) Establish and maintain centralized software baseline and status accounting records containing unique software identifiers, a brief chronology of the software items, and a description of the changes made between versions of the software items.

b) Inform management and users, upon request, of the software baseline status, including proposed, in-process, or approved changes, through the various SCM reports that comprise Status Accounting.

5.8 CHANGES TO QUALIFIED SOFTWARE AND/OR IN OPERATING SYSTEM

This section applies to changes to the following:

- Software listed on the *Baseline of Qualified Software Report*
- Operating System(s) on which that software is qualified.

Changes made to software, including any changes to documentation, shall follow the change processes in accordance with Paragraph 5.8.1.

Changes in documentation can be annotated as follows:

a) Editorial corrections may be made, as necessary, without invoking any of the change processes in Step 5.8b) as long as the RM initials and dates each editorial correction.

b) Indicate changes to the documentation by using the following:

1) A vertical line in the margin of the page, unless an extensive revision is required.

2) Include an explanation in the Change History page that clearly indicates which individual section(s) and/or subsection(s) of the affected documentation has been changed.

5.8.1 Changes to Software

5.8.1.1 Developer:

a) Prepare the SUR requesting the software for development use only by completing the Software User/Developer actions in accordance with the form instructions.

b) Submit the SUR to the Software Coordinator.

5.8.1.2 Software Coordinator:

Submit the SUR to SCM to request distribution of or access to the software item.

5.8.1.3 SCM:

a) Update Status Accounting.

b) Update the SUR by completing the SCM actions in accordance with the form instructions.

c) Provide the software package for the requested software, along with the SUR, to the Software Coordinator.

5.8.1.4 Software Coordinator:

Provide the Developer with the software package and SUR.

5.8.1.5 Developer:

a) Review the software package to ensure that all necessary elements were provided and coordinate with SCM to acquire needed elements.

b) Install the software by transferring the software elements to the development environment.

c) Update the Technical Installer actions on the SUR in accordance with the form instructions.

d) If installation failures occur, use the Software Problem Reporting and Resolution process in Subsection 5.10.

e) Return the software package and SUR with supporting documentation, if applicable, to the Software Coordinator.

5.8.1.6 Software Coordinator:

Return the software package and the SUR with supporting documentation, if applicable, to SCM.

5.8.1.7 SCM:

a) Update Status Accounting.

b) Submit the completed SUR and supporting documentation to the RPC in accordance with Section 6.0 of this procedure.

5.8.1.8 Developer:

a) Obtain the software categorization from SCM.

b) Evaluate the changes for impacts on life cycle documentation and products, as applicable.

c) Evaluate the need to perform regression testing to detect errors introduced during the modification of the software, to verify that the modifications have not caused any unintended affects, or to verify that a modified software still meets specified requirements. Changes in software media require regression testing.

d) Prepare page 1 and 2 of the SCCR by completing the Developer actions in accordance with form instructions.

e) Submit the SCCR to the RM for review and approval.

5.8.1.9 RM:

a) Review the SCCR and confirm software categorization and rationale.

b) Resolve issues with the Developer.

c) Approve the software change by completing the RM actions in accordance with form instructions.

d) Forward the SCCR to the Software Coordinator.

5.8.1.10 Software Coordinator:

Submit the SCCR to SCM.

5.8.1.11 SCM:

a) Assign the STN and software media and document number(s) by completing page 2 of the SCCR for SCM in accordance with the form instructions.

b) Update Status Accounting.

c) Provide a copy of the SCCR to the Software Coordinator and IV&V for planning purposes.

5.8.1.12 Software Coordinator:

Provide the Developer with the STN and document identifying numbers.

5.8.1.13 Developer:

Conduct software modifications in accordance with this procedure, entering the life cycle as determined on the SCCR.

5.8.2 Change in Operating System

This section is limited to changes in operating systems within the same platform and operating system series (e.g., Sun Solaris 5.6 to Sun Solaris 5.7). When the software must be recompiled or more extensive testing is required, return to Paragraph 5.8.1.

5.8.2.1 Software User:

Notify the RM of the need to use software on an operating system version for which it is not currently qualified.

5.8.2.2 RM:

Assign the Developer to test the software on the targeted operating system.

5.8.2.3 Developer:

a) Prepare the SUR requesting software for development use only by completing the Software User/Developer actions in accordance with the form instructions.

b) Prepare the SCCR page 1 and 3 by completing the Developer actions in accordance with the form instructions.

c) Submit the SCCR and SUR to the Software Coordinator.

5.8.2.4 Software Coordinator:

Submit the SCCR and SUR to SCM to request distribution of or access to the software item.

5.8.2.5 SCM:

a) Update Status Accounting.

b) Update page 1 of the SCCR by completing the SCM actions in accordance with the form instructions.

c) Update the SUR by completing the SCM actions in accordance with the form instructions.

d) Forward the requested software package and SUR to the Software Coordinator.

5.8.2.6 Software Coordinator:

Provide the Developer with the software package and SUR.

5.8.2.7 Developer:

a) Install the software on the target platform in accordance with the applicable installation instructions.

b) Update the Technical Installer actions on the SUR in accordance with the form instructions.

c) Return the software package and SUR with supporting documentation, if applicable, to the Software Coordinator.

5.8.2.8 Software Coordinator:

a) If installation was not successful, submit the software package, SUR, and supporting documentation to SCM.

b) If installation was successful, submit the software package, SUR, and supporting documentation to IV&V.

5.8.2.9 IV&V:

Initiate IV&V for Operating System Change in accordance with AP-SI.3Q.

5.8.2.10 SCM

a) Review the SCCR, as appropriate, verifying that the operating system and version on page 3 of the SCCR are correct by completing the SCM actions in accordance with the form instructions.

b) Update Status Accounting.

c) Process the record copies of the software, SCCR, SUR, and all Operating System Change documentation.

d) Submit the records to the RPC in accordance with Section 6.0 of this procedure.

e) Notify the Software Coordinator that the Operating System change is complete and provide the Software Coordinator with a copy of the SCCR.

5.8.2.11 Software Coordinator:

Notify the Developer and Software User of the software status.

5.8.3 Software Not Qualified for the Targeted Validation Range

This section is limited to software already on the *Baseline of Qualified Software Report*, but that is not qualified for the targeted validation range.

5.8.3.1 Software User:

Notify the RM of the need to use software for validation ranges for which it is not currently qualified.

5.8.3.2 RM:

Assign the Developer to test the software for the targeted validation range.

5.8.3.3 Developer:

Proceed to Paragraph 5.8.1.1.

5.9 USE OF UNKNOWN OR INDETERMINATE PEDIGREE SOFTWARE

This subsection describes the steps to be performed to disposition historical software that has been discovered in the OCRWM data and/or records suite, but whose pedigree is questionable or unknown. The software is not on the *Baseline of Qualified Software Report*.

RM:

Qualify unknown or indeterminate pedigree software beginning with Subsection 5.2.

5.10 QUALIFIED SOFTWARE PROBLEM REPORTING AND RESOLUTION

This subsection describes the steps to be performed upon identification of a problem in any qualified software item.

5.10.1 RM/Software User/Technical Installer:

a) Note the reproducibility of the problem (whether consistent or intermittent). If the problem report is originated from outside the OCRWM program, attempt to replicate the supplier-identified problem in the local environment.

b) Verify, in conjunction with the developing organization or supplier, that the problem is an actual software problem and not user induced.

c) If the problem is determined to be user induced, stop the process. If the problem is not user induced, document the problem and the environment under which it occurred, on Attachment 5, Software Problem Report, in accordance with form instructions.

d) Attach the supplier notification/documentation to the Software Problem Report (SPR) if the problem was discovered from a source outside of the program.

e) Submit the SPR to SCM.

5.10.2 SCM:

a) Assign an SPR number by completing the SCM actions in accordance with the form instructions.

b) Remove software from the baseline until Paragraph 5.10.3 is complete.

c) Identify the affected organizations.

d) Submit a copy of the SPR to the RMs for those Affected Organizations and to any identified users of the software within those Affected Organizations.

e) Coordinate notification to the supplier of acquired, unmodified software, if applicable.

f) Provide a copy of the SPR and any supporting documentation to the RM of the Developing Organization.

5.10.3 RM:

a) Conduct an impact evaluation of past and present applications of the software on technical product(s) or data sets and document the results including any preventative and corrective actions. Include a statement of the impact of the error or defect specifying one of the following conditions:

- No impact exists (with detailed rationale for the determination of no impact).
- Insignificant impact exists (with detailed rationale for the determination of significance).
- A condition exists that is adverse to quality, including safety and health conditions.

b) If a condition exists that is adverse to quality, initiate corrective action under AP-16.1Q, *Management of Conditions Adverse to Quality*.

c) If any of the output, generated, or developed data from the software has been submitted to the Technical Data Management System and is adversely affected, notify the Technical Data Management Organization of the problem and its effect on ongoing and previous quality-affecting work.

d) Determine whether a modification to the software and/or accompanying baseline documentation is appropriate if the software problem is determined not to affect ongoing or previous quality-affecting work.

e) If modification is appropriate, begin in accordance with Paragraph 5.8.1.

f) Submit the copy of the SPR and any supporting documentation to SCM.

5.10.4 SCM:

a) Perform the appropriate Status Accounting activities required to update the software baseline.

b) Submit the completed SPR and supporting documentation to the RPC, in accordance with Section 6.0 of this procedure, as part of the complete records package compilation.

c) Notify all documented users of the disposition of the software, and include preventive actions and corrective actions, as applicable.

5.11 CONTINUOUS OPERATION SOFTWARE

Software that is acquired or developed to perform continuous data acquisition or process control functions shall have additional in-use tests in order to provide confirmation of correct results of the software.

5.11.1 RM:

a) Define periodic manual or automatic self-check, in-use tests as an element of the software's qualification package. In-use tests shall be performed for any software where computer errors, data errors, computer hardware failures, or instrument drift can affect the required performance. The frequency of the in-use test is determined by the RM.

b) Document and verify, with reliable evidence, that the tests have been conducted and the software is still operating as designed and implemented. Documentation shall consist of the following elements:

- Date the test was conducted
- Person conducting the test
- Test case(s) used
- Results of the test.

c) Forward the original or a copy of any in-use test documentation to the Software Coordinator.

d) If objective evidence is found that the software is not operating as designed and implemented, follow the steps in Subsection 5.10.

5.11.2 Software Coordinator:

Submit the in-use test documentation to SCM.

5.11.3 SCM:

Submit in-use test documentation to the RPC in accordance with Section 6.0 of this procedure as individual records.

6.0 RECORDS

The records listed in Subsection 6.1 shall be collected and submitted to the RPC in accordance with AP-17.1Q, *Record Source Responsibilities for Inclusionary Records*, as individual records or included in a records package, as specified. In the event the RPC requires editorial corrections per AP-17.1Q, SCM is authorized to make required changes to the baseline documentation.

6.1 QA RECORDS

Control Point B Records Package for Level B Software:

SCCR
SMR
SMR Verification Report
Control Point B Report

Cancelled Software Records Package:

SCCR

Retired Software Records Package:

SCCR
User Concurrences

Operating System Change Records Package:

SCCR
SUR
Supporting Documentation
Operating System Change Report

Problem Report Records Package:

SPR
Supporting Documentation

Individual Records:

SUR
In-Use Test Documentation

6.2 NON-QA INCLUSIONARY RECORDS

None

6.3 NON-QA EXCLUSIONARY RECORDS

None

7.0 REFERENCES

a) *Quality Assurance Requirements and Description*, DOE/RW-0333P
b) AP-3.11Q, *Technical Reports*
c) AP-3.12Q, *Design Calculations and Analyses*
d) AP-3.19Q, *Specifications*
e) AP-3.24Q, *Drawings*
f) AP-12.1Q, *Control of Measuring and Test Equipment and Calibration Standards*
g) AP-16.1Q, *Management of Conditions Adverse to Quality*
h) AP-17.1Q, *Record Source Responsibilities for Inclusionary Records*
i) AP-IM-002, *Use of Copyright-Protected Materials*
j) AP-SI.2Q, *Qualification of Level A Software*
k) AP-SI.3Q, *Software Independent Verification and Validation*
l) AP-SIII.9Q, *Scientific Analyses*
m) AP-SIII.10Q, *Models*
n) AP-SV.1Q, *Control of the Electronic Management of Information*

8.0 ATTACHMENTS

Forms attached to this procedure are controlled and distributed as full-size pages separate from this procedure and may be copied for use when implementing this procedure.

Attachment 1 - Software User Request (Form ASI1-4)
Attachment 2 - AP-SI.1Q Flowcharts
Attachment 3 - Acronyms and Abbreviations
Attachment 4 - Software Configuration Control Request (Form ASI1-1)
Attachment 5 - Software Problem Report (Form ASI1-2)

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
SOFTWARE USER REQUEST

QA: QA
Page: 1 of: 1

Complete Only Applicable Items

1. STN	2. Software Name	3. Version

4. Organization	5. Software User

6. Use of Software

EXAMPLE

7.

☐ Single Computer ☐ Single Server Access ☐ Multiple (Global) Access
☐ Read ☐ Read
☐ Read/Write ☐ Read/Write

8. Responsible Manager Name	9. Responsible Manager Organization	10. Date
11. Responsible Manager Telephone		
12. SCM Name		13. Date

14.

☐ Installation/Reinstallation successful ☐ Installation failed ☐ Supporting documentation

15. Installer Name	16. Signature	17. Date

AP-SL.1Q FORM NO. ASI1-4 Rev. 04/23/2003

Attachment 1 - Software User Request

INSTRUCTIONS FOR COMPLETING THE SOFTWARE USER REQUEST

Software User/Developer

1. STN - Enter the STN from the *Baseline of Qualified Software Report*.

2. SOFTWARE NAME - Enter the Software Name.

3. VERSION - Enter the Software Version number.

4. ORGANIZATION - Enter the Software User's Organization.

5. SOFTWARE USER - Enter the Software User's name(s). Attach list of users if more than one.

6. USE OF SOFTWARE - State the intended use of the software, and identify the activities/product(s) the software will be used to support (e.g., an Analysis Model Report, and specify the CPU Identifier[s] [barcode or serial #], platform, and operating system). **Indicate if the requested software is for development use only.**

7. Mark if the software is to be distributed or installed on a single computer, or is it to be mounted on a server that can be accessed by multiple persons. Further indicate if this server access is for a single user (read or read/write) or if the software has been developed for OCRWM-wide, global access (read or read/write).

8. RESPONSIBLE MANAGER NAME - Enter the Responsible Manager's Name (signature is not required).

9. RESPONSIBLE MANAGER ORGANIZATION - Enter the Responsible Manager's Organization.

10. DATE - Enter today's Date.

11. RESPONSIBLE MANAGER TELEPHONE - Enter the Responsible Manager's Telephone number.

Software Configuration Management

12. SCM NAME - Enter SCM Name (signature is not required).

13. DATE - Enter SCM process Date.

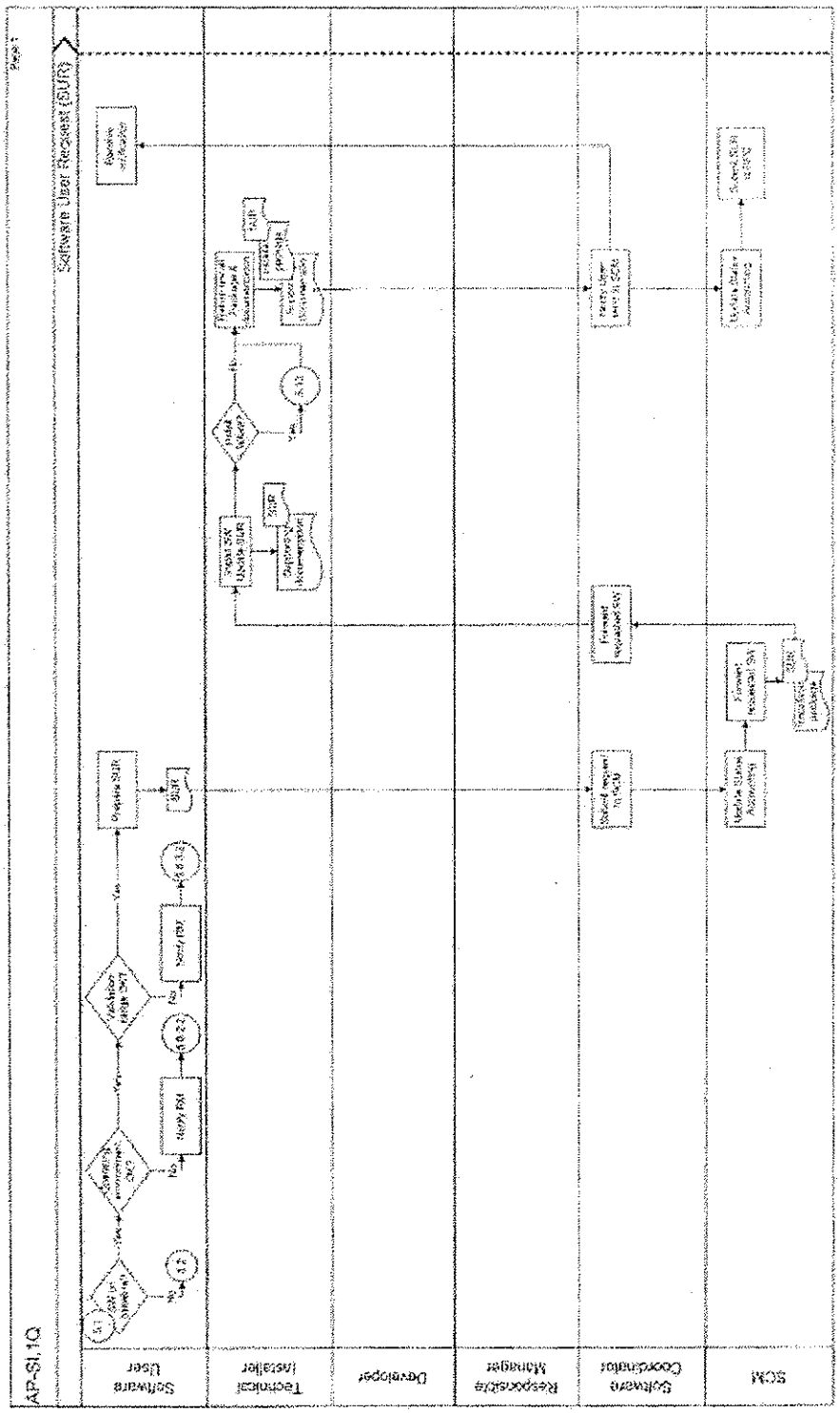
Technical Installer

14. After successful installation, check the appropriate boxes; attach any supporting documentation. If the installation failed, indicate the failure in block 14 and attach any supporting documentation.

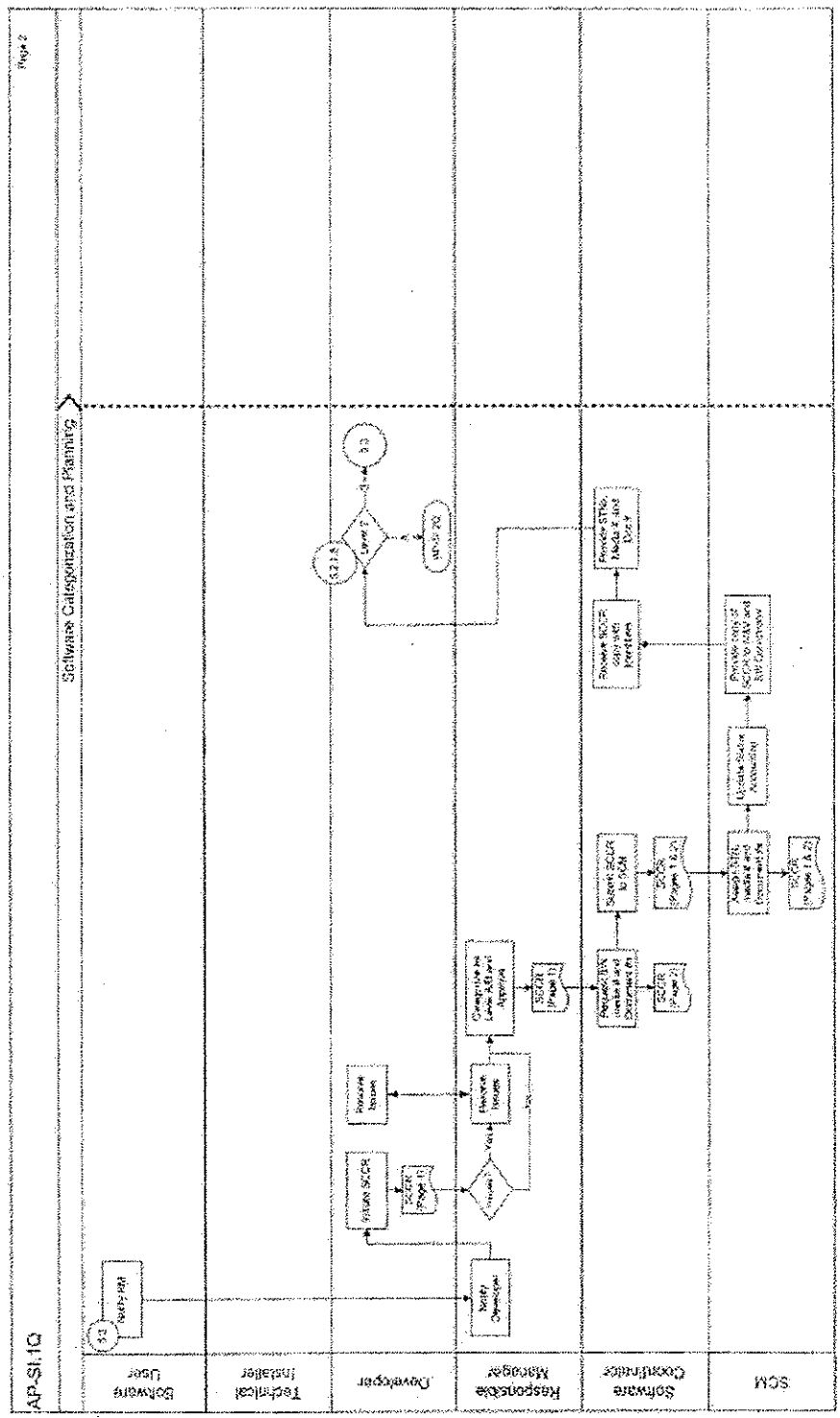
15. INSTALLER NAME - Enter the Installer Name.

16. SIGNATURE - Enter the Signature of Installer.

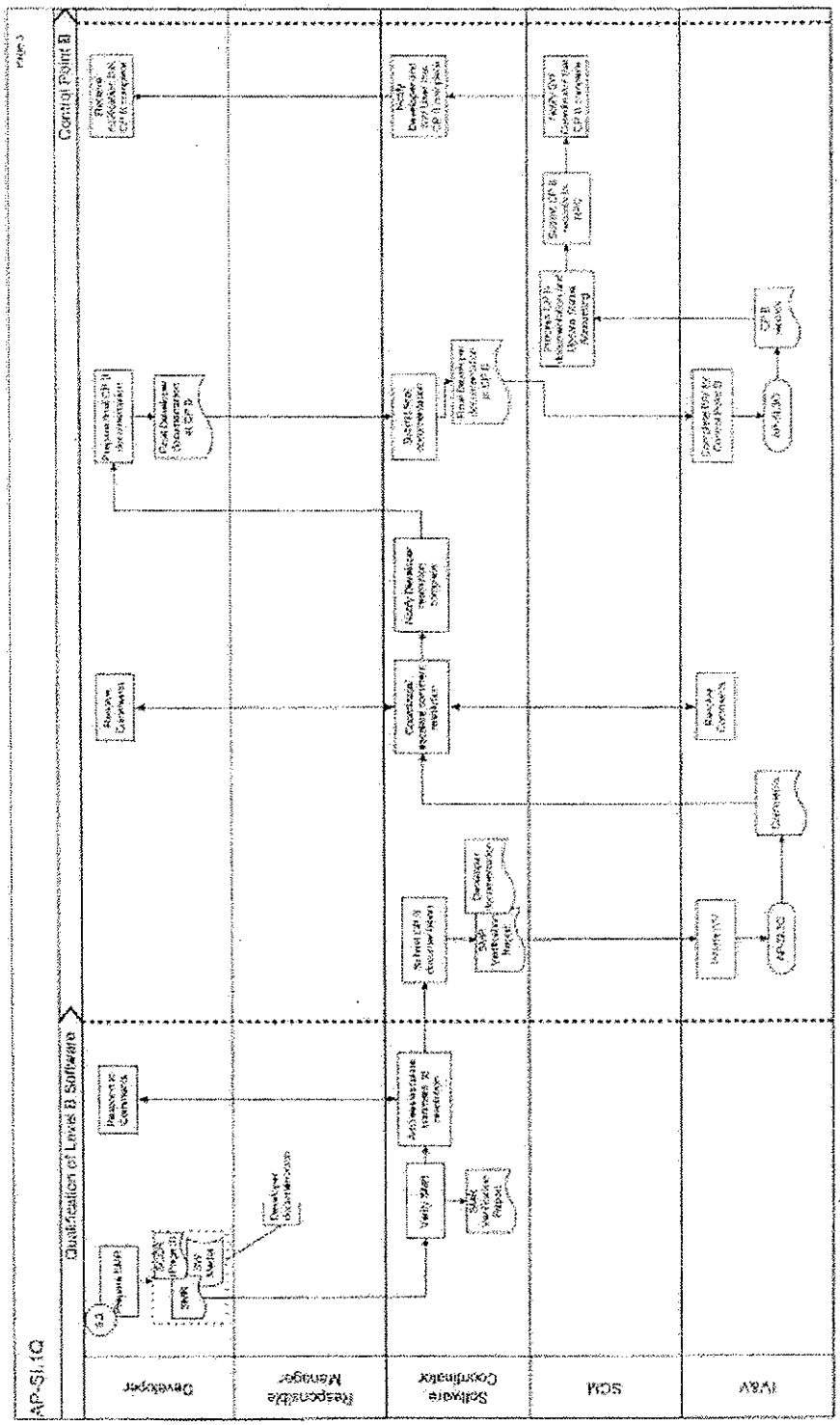
17. DATE - Enter the Date the Installer signed.



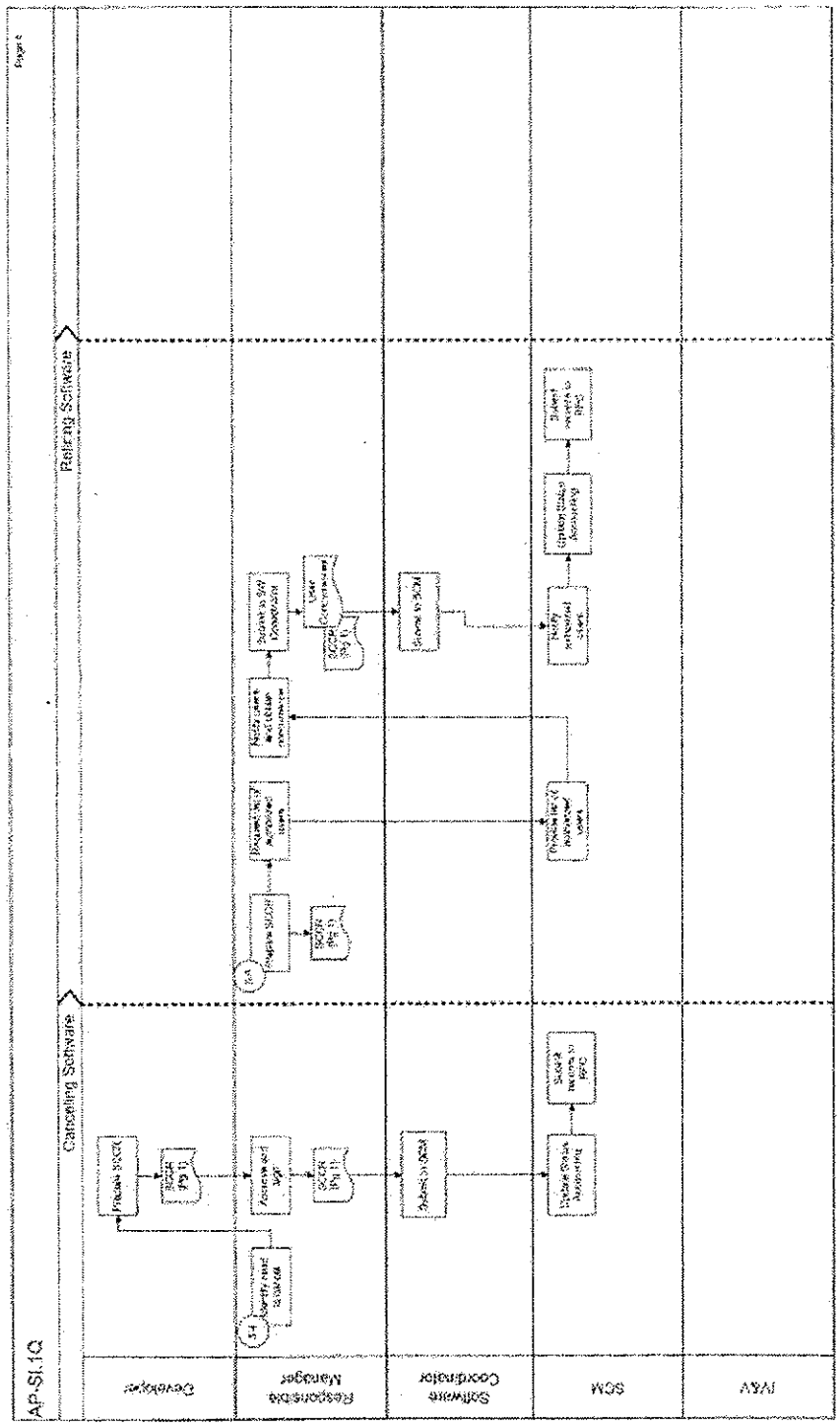
Attachment 2 - AP-SI.1Q Flowchart



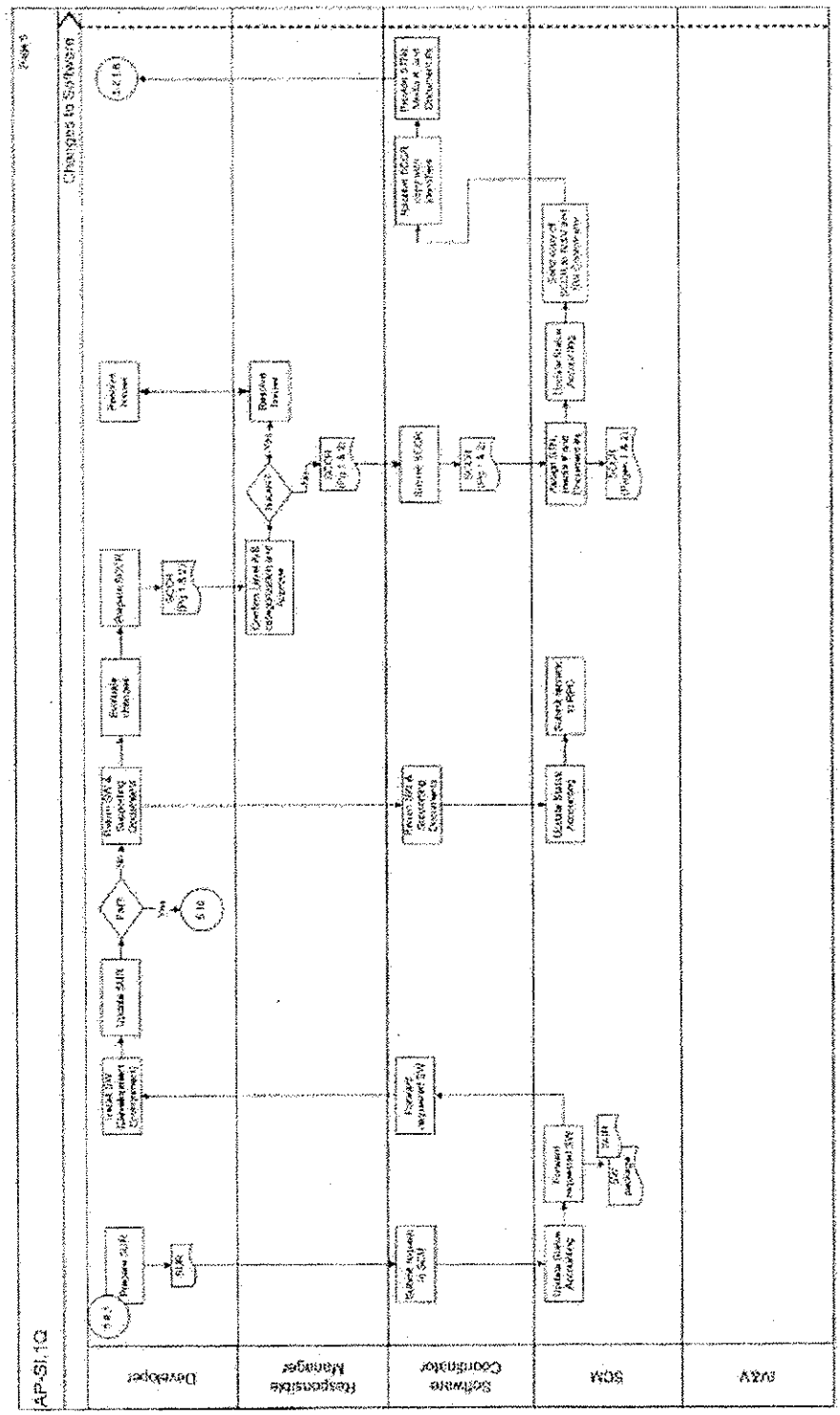
Attachment 2 - AP-SI.1Q Flowchart (Continued)



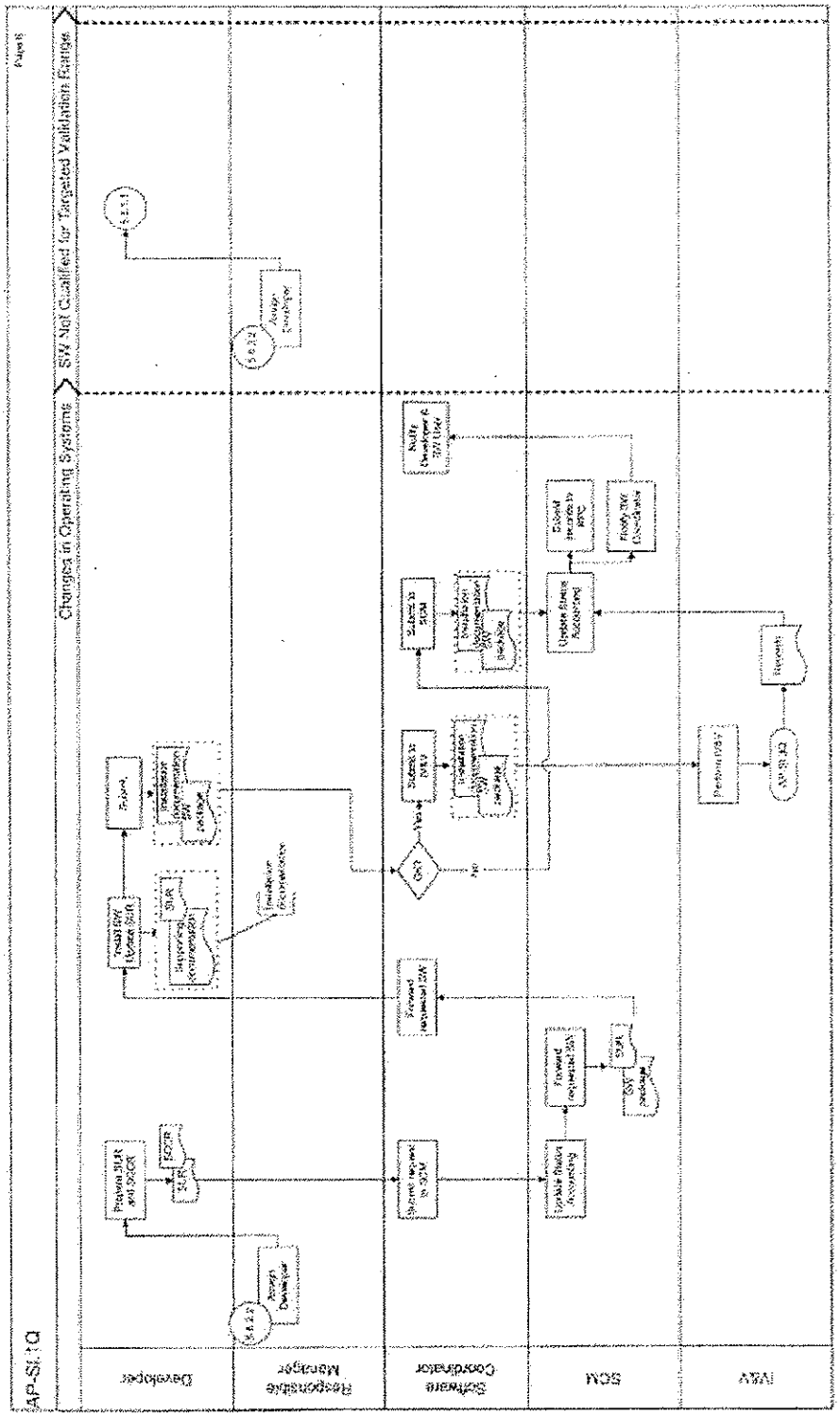
Attachment 2 - AP-SI.1Q Flowchart (Continued)



Attachment 2 - AP-SL.1Q Flowchart (Continued)



Attachment 2 - AP-SI.1Q Flowchart (Continued)



Attachment 2 - AP-SI.1Q Flowchart (Continued)

ITP	Installation Test Process
IV&V	Independent Verification and Validation
OCRWM	Office of Civilian Radioactive Waste Management
QA	Quality Assurance
QARD	Quality Assurance Requirements and Description
RD	Requirements Document
RM	Responsible Manager
RPC	Records Processing Center
SCM	Software Configuration Management
SCCR	Software Configuration Control Request
SPR	Software Problem Report
SMR	Software Management Report
STN	Software Tracking Number
SUR	Software User Request
VTP	Validation Test Process
VTR	Validation Test Report

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT QA: QA
SOFTWARE CONFIGURATION CONTROL REQUEST Page: 1 of:

Complete Only Applicable Items

1. STN	2. Software Name	3. Version
4. Organization	5. Developer/RM	
6. Action ☐ New ☐ Revision	7. Action Type	
8. Category	9. Request Date	
10. Software Source ☐ Acquired ☐ Developed	11. Vendor/In-House	

12. Software Description

EXAMPLE

13. Justification (Intended program use)

14. SCM (Printed Name)	15. Signature	16. Date Received
		17. Date Entered
18. RM (Printed Name)	19. Signature	20. Date

AP-SI.1Q FORM NO. ASI1-1 Rev. 04/23/2003

Attachment 4 - Software Configuration Control Request

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT QA: QA
SOFTWARE CONFIGURATION CONTROL REQUEST Page: 2 of:

Complete Only Applicable Items

1. STN	2. Software Name	3. Version

4. Organization	5. Developer/RM

21. EFL	DOCUMENT	ACRONYM	22. DOCUMENT ID	23. COMMENTS
	Requirements Document	RD		
	Design Document	DD		
	Installation Test Process	ITP		
	Validation Test Process	VTP		
	RD Verification Report			
	User's Manual	UM		
	Validation Test Report	VTR		
	DD Verification Report			
	Software Management Report	SMR		
	SMR Verification Report			
	Media			
	Control Point A Report	VVAR		
	Control Point B Report	VVBR		
	Software OS Change Report	OSCR		

EXAMPLE

24. Other Continuation Information

25. SCM (Printed Name)	26. Signature	27. Date

AP-SI.1Q FORM NO. ASII-1 Rev. 04/23/2003

Attachment 4 - Software Configuration Control Request (Continued)

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT QA: QA
SOFTWARE CONFIGURATION CONTROL REQUEST Page: 3 of:

Complete Only Applicable Items

1. SYN	2. Software Name	3. Version

4. Organization	5. Developer/RM

28. Limitations on Installation Use (e.g., passwords to install software, hardware keyfuse (dongle requirements)

EXAMPLE

29. Software Key?	30. Hardware Key?
☐ Yes ☐ No	☐ Yes ☐ No

List all platforms and operating systems

31. Platform(s)	32. Operating System(s)

33. SCM (Printed Name)	34. Signature	35. Date

AP-SI.1Q FORM NO. ASR-1 Rev. 04/23/2003

Attachment 4 - Software Configuration Control Request (Continued)

INSTRUCTIONS FOR COMPLETING THE SOFTWARE CONFIGURATION CONTROL REQUEST

SOFTWARE CATEGORIZATION EVALUATION FOR SOFTWARE NOT ON THE *BASELINE OF QUALIFIED SOFTWARE REPORT*

PAGE 1 INSTRUCTIONS

Developer

2. SOFTWARE NAME - Enter Software Name.

3. VERSION - Enter the Version of the software being used. If unknown, leave blank when initially registering the software.

4. ORGANIZATION - Enter the appropriate Organizational identifier (e.g., Los Alamos National Laboratory [LANL], Lawrence Berkeley National Laboratory [LBNL], Lawrence Livermore National Laboratory [LLNL], Sandia National Laboratories [SNL], U.S. Geological Survey [USGS], Bechtel SAIC Company, LLC [BSC]).

5. DEVELOPER/RM - Enter the first and last name of the Developer or Responsible Manager.

6. ACTION - Select the applicable action (New or Revision).

7. ACTION TYPE - Enter the Action Type (e.g., New, Modify).

9. REQUEST DATE - Enter the Request Date.

10. SOFTWARE SOURCE - Identify the original source:

    - Procurement = Software acquired externally
    - Development = Software developed internally.

11. VENDOR/IN-HOUSE DEVELOPER - If the software was acquired from a Vendor, enter the Vendor's name or N/A if unknown. If the software was developed In-House, enter the name of the developer, if available.

12. SOFTWARE DESCRIPTION - Enter a brief description (overall nature, function, and purpose) of the software. When "Action" is "Revision," enter a description of the change. Information may be continued on page 2 (Block 24) of this SCCR.

13. JUSTIFICATION (INTENDED PROGRAM USE) - Enter a brief justification as related to the selected action. Information may be continued on page 2 (Block 24) of this SCCR.

Responsible Manager

8. CATEGORY - Assign an appropriate software Category (A or B).

18. RM - Enter the Name of the Responsible Manager.

19. SIGNATURE - Enter the Signature of the Responsible Manager approving the category assigned.

20. DATE - Enter the Date the Responsible Manager signed.

INSTRUCTIONS FOR COMPLETING THE SOFTWARE CONFIGURATION CONTROL REQUEST (CONTINUED)

SOFTWARE CATEGORIZATION EVALUATION FOR SOFTWARE NOT ON THE *BASELINE OF QUALIFIED SOFTWARE REPORT*

PAGE 1 INSTRUCTIONS (CONTINUED)

Software Configuration Management

16. DATE RECEIVED - Enter the date received by SCM.

1. STN - Enter the Software Tracking Number.

14. SCM - Enter the Name of SCM.

15. SIGNATURE - Enter the Signature of SCM.

17. DATE ENTERED - Enter the Date SCM updated Status Accounting.

INSTRUCTIONS FOR COMPLETING THE SOFTWARE CONFIGURATION CONTROL REQUEST (CONTINUED)

SOFTWARE CATEGORIZATION EVALUATION FOR SOFTWARE NOT ON THE *BASELINE OF QUALIFIED SOFTWARE REPORT*

PAGE 2 INSTRUCTIONS

Software Coordinator

Ensure that Blocks 2-5 are completed correctly.

21. SEL/DOCUMENT - Check the Documents that will be submitted for the software.

Software Configuration Management

1. STN - Enter the Software Tracking Number.

22. DOCUMENT ID - Enter the document ID number.

23. COMMENTS - Enter additional COMMENTS or links to other documents.

24. CONTINUATION INFORMATION - Enter additional information for form fields, if necessary.

25. SCM - Enter the Name of SCM.

26. SIGNATURE - Enter the Signature of SCM.

27. DATE - Enter the Date SCM signed.

INSTRUCTIONS FOR COMPLETING THE SOFTWARE CONFIGURATION CONTROL REQUEST (CONTINUED)

SOFTWARE CATEGORIZATION EVALUATION FOR SOFTWARE NOT ON THE *BASELINE OF QUALIFIED SOFTWARE REPORT*

PAGE 3 INSTRUCTIONS

Developer

Ensure that Blocks 1-5 are completed correctly.

26. LIMITATIONS ON INSTALLATION USE - List the limitations on use or N/A. For example, specify any license restrictions and/or requirements for installation such as password requirement and/or hardware key/use dongle requirements.

29. SOFTWARE KEY? - Select Yes or No.

30. HARDWARE KEY? - Select Yes or No.

31. PLATFORM(S) - List all hardware platforms that are to be qualified. (Note: Requires test results in Validation Test Report (VTR) or SMR.)

32. OPERATING SYSTEM(s) - List Operating System(s) that is to be qualified. (Note: Requires test results in VTR or SMR.)

Software Configuration Management

33. SCM - Enter the Name of SCM.

34. SIGNATURE - Enter the Signature of SCM.

35. DATE - Enter the Date SCM signed.

INSTRUCTIONS FOR COMPLETING THE SOFTWARE CONFIGURATION CONTROL REQUEST

CANCELING SOFTWARE

PAGE 1 INSTRUCTIONS

Developer

1. STN - Enter the Software Tracking Number of the Software to be canceled.
2. SOFTWARE NAME - Enter the Name of the Software to be canceled.
3. VERSION - Enter the Version of the Software to be canceled.
4. ORGANIZATION - Enter the appropriate Organizational identifier.
5. DEVELOPER/RM - Enter the first and last name of the Developer.
6. ACTION - Select the applicable action (Revision).
7. ACTION TYPE - Enter the Action Type (Cancel).
8. CATEGORY - Enter the Software Category (A or B).
9. REQUEST DATE - Enter the Request Date.
10. SOFTWARE SOURCE - Identify the original source.
11. VENDOR/IN-HOUSE DEVELOPER - If the software was acquired from a Vendor, enter the Vendor's name or N/A if unknown. If the software was developed In-House, enter the name of the developer, if available.
12. SOFTWARE DESCRIPTION - Leave blank
13. JUSTIFICATION (INTENDED PROGRAM USE) - Enter the rationale for the cancellation of the Software.

Responsible Manager

18. RM - Enter the Name of the Responsible Manager.
19. SIGNATURE - Enter the Signature of the Responsible Manager approving the Software cancellation.
20. DATE - Enter the Date the Responsible Manager signed.

Software Configuration Management

16. DATE RECEIVED - Enter the date received by SCM.
14. SCM - Enter the Name of SCM.
15. SIGNATURE - Enter the Signature of SCM.
17. DATE ENTERED - Enter the Date SCM updated Status Accounting.

PAGE 2 AND PAGE 3 OF THE SCCR ARE NOT USED FOR CANCELING SOFTWARE

INSTRUCTIONS FOR COMPLETING THE SOFTWARE CONFIGURATION CONTROL REQUEST

RETIRING SOFTWARE

PAGE 1 INSTRUCTIONS

Responsible Manager

1. STN - Enter the Software Tracking Number of the Software to be retired.
2. SOFTWARE NAME - Enter the Name of the Software to be retired.
3. VERSION - Enter the Version of the Software to be retired.
4. ORGANIZATION - Enter the appropriate Organizational identifier.
5. DEVELOPER/RM - Enter the first and last name of the Responsible Manager.
6. ACTION - Select the applicable action (New).
7. ACTION TYPE - Enter the Action Type (Retire).
8. CATEGORY - Enter the Software Category (A or B).
9. REQUEST DATE - Enter the Request Date.
10. SOFTWARE SOURCE - Identify the original source.
11. VENDOR/IN-HOUSE DEVELOPER - If the software was acquired from a Vendor, enter the Vendor's name or N/A if unknown. If the software was developed In-House, enter the name of the developer, if available.
12. SOFTWARE DESCRIPTION - If Software is qualified for multiple environments, identify the environment to be retired (e.g. WIN95), or enter "ALL."
13. JUSTIFICATION (INTENDED PROGRAM USE) - Enter the rationale for the retirement of the Software.

Software Configuration Management

16. DATE RECEIVED - Enter the date received by SCM.
14. SCM - Enter the Name of SCM.
15. SIGNATURE - Enter the Signature of SCM.
17. DATE ENTERED - Enter the Date SCM updated Status Accounting.

PAGE 2 AND PAGE 3 OF THE SCCR ARE NOT USED FOR RETIRING SOFTWARE

INSTRUCTIONS FOR COMPLETING THE SOFTWARE CONFIGURATION CONTROL REQUEST

CHANGES TO QUALIFIED SOFTWARE

PAGE 1 INSTRUCTIONS

Developer

2. SOFTWARE NAME - Enter the Name of the Software to be changed.

3. VERSION - Enter the "new" Version of the Software.

4. ORGANIZATION - Enter the appropriate Organizational identifier.

5. DEVELOPER/RM - Enter the first and last name of the Developer or Responsible Manager.

6. ACTION - Select the applicable action (New).

7. ACTION TYPE - Enter the Action Type (Modify).

8. CATEGORY - Enter the Software Category (A or B).

9. REQUEST DATE - Enter the Request Date.

10. SOFTWARE SOURCE - Identify the original source.

11. VENDOR/IN-HOUSE DEVELOPER - If the software was acquired from a Vendor, enter the Vendor's name or N/A if unknown. If the software was developed In-House, enter the name of the developer, if available.

12. SOFTWARE DESCRIPTION - Enter a description and scope of the change.

13. JUSTIFICATION (INTENDED PROGRAM USE) - Enter the rationale for the change to the Software. Information may be continued on page 2 (Block 24) of this SCCR.

Responsible Manager

18. RM - Enter the Name of the Responsible Manager.

19. SIGNATURE - Enter the Signature of the Responsible Manager approving the Software change.

20. DATE - Enter the Date the Responsible Manager signed.

Software Configuration Management

16. DATE RECEIVED - Enter the date received by SCM.

1. STN - Enter the Software Tracking Number.

14. SCM - Enter the Name of SCM.

15. SIGNATURE - Enter the Signature of SCM.

17. DATE ENTERED - Enter the Date SCM updated Status Accounting.

INSTRUCTIONS FOR COMPLETING THE SOFTWARE CONFIGURATION CONTROL REQUEST (CONTINUED)

CHANGES TO QUALIFIED SOFTWARE

PAGE 2 INSTRUCTIONS

Developer

Ensure that Blocks 1-5 are completed correctly.

24. CONTINUATION INFORMATION - Document the if regression testing was needed, and if so include the results.

21. SEL/DOCUMENT - Check the Documents changed.

22. DOCUMENT ID - Enter the document ID number(s) for unchanged Documents and/or Software Media.

Software Configuration Management

1. STN - Enter the Software Tracking Number.

22. DOCUMENT ID - Enter the document ID number(s) for changed Documents and/or Software Media.

23. COMMENTS - Enter additional COMMENTS or links to other documents.

24. CONTINUATION INFORMATION - Enter additional information for form fields, if necessary.

25. SCM - Enter the Name of SCM.

26. SIGNATURE - Enter the Signature of SCM.

27. DATE - Enter the Date SCM signed.

PAGE 3 OF THE SCCR IS NOT USED FOR CHANGING SOFTWARE

INSTRUCTIONS FOR COMPLETING THE SOFTWARE CONFIGURATION CONTROL REQUEST

CHANGES TO OPERATING SYSTEM

PAGE 1 INSTRUCTIONS

Developer

2. SOFTWARE NAME - Enter the Name of the Software whose Operating System is to be changed.

3. VERSION - Enter the Version of the Software.

4. ORGANIZATION - Enter the appropriate Organizational identifier.

5. DEVELOPER/RM - Enter the first and last name of the Developer or Responsible Manager.

6. ACTION - Select the applicable action (New).

7. ACTION TYPE - Enter the Action Type (New).

8. CATEGORY - Enter the Software Category (A or B).

9. REQUEST DATE - Enter the Request Date.

10. SOFTWARE SOURCE - Identify the original source.

11. VENDOR/IN-HOUSE DEVELOPER - If the software was acquired from a Vendor, enter the Vendor's name or N/A if unknown. If the software was developed In-House, enter the name of the developer, if available.

12. SOFTWARE DESCRIPTION - Enter a description and scope of the change.

13. JUSTIFICATION (INTENDED PROGRAM USE) - Enter the rationale for the change in Operating System for the Software.

Responsible Manager

18. RM - Enter the Name of the Responsible Manager.

19. SIGNATURE - Enter the Signature of the Responsible Manager approving the Operating System change.

20. DATE - Enter the Date the Responsible Manager signed.

Software Configuration Management

16. DATE RECEIVED - Enter the date received by SCM.

1. STN - Enter the Software Tracking Number.

14. SCM - Enter the Name of SCM.

15. SIGNATURE - Enter the Signature of SCM.

17. DATE ENTERED - Enter the Date SCM updated Status Accounting.

PAGE 2 OF THE SCCR IS NOT USED FOR OPERATING SYSTEM CHANGES

INSTRUCTIONS FOR COMPLETING THE SOFTWARE CONFIGURATION CONTROL REQUEST (CONTINUED) CHANGES TO OPERATING SYSTEM

PAGE 3 INSTRUCTIONS

Developer

Ensure that Blocks 2-5 are completed correctly.

28. LIMITATIONS ON INSTALLATION USE - List the limitations on use or N/A. For example, specify any license restrictions and/or requirements for installation such as password requirement and/or hardware key/use dongle requirements.

29. SOFTWARE KEY? - Select Yes or No.

30. HARDWARE KEY? - Select Yes or No.

31. PLATFORM(S) - List hardware platforms that are to be qualified. (Note: Requires test results in VTR or SMR.)

32. OPERATING SYSTEM(s) - List "new" Operating System(s) that is to be qualified. (Note: Requires test results in VTR or SMR.)

Software Configuration Management

1. STN - Enter the Software Tracking Number.

33. SCM - Enter the Name of SCM.

34. SIGNATURE - Enter the Signature of SCM.

35. DATE - Enter the Date SCM signed.

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SOFTWARE PROBLEM REPORT Page: 1 of

Complete Only Applicable Items

1. Software Tracking Number:	2. Software Name and Version:	3. Software Activity Number:

4. Source of Problem:

☐ Internal to OCRWMS

☐ External to OCRWMS (Supplier or Outside User)

Name (if available) _____

Address (if available) _____

Phone (if available) _____

5. Date Problem Encountered:	6. Has Problem Been Verified? ☐ Yes ☐ No

7. Document the environment under which problem occurred (such as Operating System, Switch Settings, Location in the Code, and the Input Range where the problem occurred) or attach a copy of the error notice/documentation received from the supplier and include a proposed resolution:

EXAMPLE

8. User or Developer Name:	User or Developer Org.:	Date:
9. Software Status Accounting Name and Signature:	Software Status Accounting SPR Number:	Date:
10. Software Configuration Management Verifier Name and Signature:		Date:
11. Software Configuration Management Name and Signature:		Date:

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INSTRUCTIONS FOR COMPLETING THE SOFTWARE PROBLEM REPORT

RM/Software User/Technical Installer

1. Software Tracking Number - Enter the previously assigned Software Tracking Number.

2. SOFTWARE NAME AND VERSION - Enter the Software Name and Version number.

3. SOFTWARE ACTIVITY NUMBER - Enter the previously assigned Software Activity Number for this software.

4. SOURCE OF PROBLEM - Indicate whether the problem was internally discovered or came from an external source by checking the appropriate box. Provide the supplier or outside user name, address, and telephone number, if known; otherwise, N/A.

5. DATE PROBLEM ENCOUNTERED - Enter the Date the problem was first discovered or made known to you.

6. HAS THE PROBLEM BEEN VERIFIED? - Indicate if the problem has been verified (reproduced) by checking Yes or No.

7. DOCUMENT THE ENVIRONMENT ... - Provide a description of the problem and give as much detail as possible, including where in the software code (what module, if any) the problem occurred, and under what conditions. Attach a copy of the notification/documentation from the supplier and reference the attachment in this block. Include a proposed resolution.

8. USER OR DEVELOPER NAME - Enter the User or Developer Name (signature is not required), Organization, and Date.

Software Configuration Management

9. SOFTWARE STATUS ACCOUNTING NAME AND SIGNATURE - Enter the Software Status Accounting Name and Signature, Software Status Accounting SPR Tracking Number, and Date.

10. SOFTWARE CONFIRGURATION MANAGEMENT VERIFIER NAME AND SIGNATURE - The SCM Verifier will review the problem and verify the documentation. Fill out the SCCR (page 3) requesting that software be removed from use until the Responsible Manager has conducted an evaluation and provided a statement of the impact of the problem. Attach the SCCR (page 3) to this form and give it to SCM. Enter the Software Configuration Management Verifier Name, Signature, and Date.

11. SOFTWARE CONFIRGURATION MANAGEMENT NAME AND SIGNATURE - Enter the Software Configuration Management Name and Signature. Ensure that the software has been removed from the *Baseline of Qualified Software Report* for approved Project use. Enter the Date SCM signed.

ENCLOSURE

#5

I.1 GENERAL

This supplement establishes requirements for the development, modification, control, and use of software. Software that is acquired as an integral part of measuring and test equipment, and has not been developed or modified by the Affected Organization, is controlled by Section 12.0, Control of Measuring and Test Equipment, and is exempt from the requirements of this supplement. Requirements for electronic management of data are addressed in Supplement V, Control of the Electronic Management of Data.

The following types of software are not required to be qualified using this supplement: operating systems; administrative and management systems; system utilities and compilers and their associated libraries; and software that does not generate data such as word processing programs, spreadsheets, database managers, graphing and visual display software, and statistical analysis programs. However, applications written for use within these types of software may need to meet the requirements for the software covered by this supplement or may need Supplement V, Control of the Electronic Management of Data.

I.2 REQUIREMENTS

I.2.1 Software Life Cycles, Baselines, and Controls

A. For developed or modified software, each Affected Organization shall document and approve a specific software life cycle for each software item prior to development or modification of software.

1. Software life cycles shall be defined by control points at which software baseline elements shall be documented. Software life cycle activities may be performed in an iterative or sequential manner.

2. When the software life cycle is defined for software development or modification within an Affected Organization, the documentation requirements of Subsections I.2.3, Software Verification, B and C, I.2.4, Software Validation, F and G, and I.2.5, Documentation, A, B, and C shall be established. All other requirements apply subsequent to establishment of the software life cycle.

3. Reviews of software baselines shall be performed and documented at the software control points.

B. For acquired software the following requirements shall be met:

1. Perform installation tests to ensure that software performs as required in the operational environment.

2. Perform validation in accordance with Subsection I.2.4, Software Validation, D, E, F, and G using test cases developed independently of the software developer. Additional test cases provided by the developer may be used to supplement this process with justification for their use.

3. Document in accordance with the requirements of Subsection I.2.5, Documentation, A, B, C.2, and C.6 as applicable.

4. Perform and document reviews of software baselines.

5. Place under the configuration controls in accordance with Subsection I.2.6, Software Configuration Management.

6. Implement a defect reporting and resolution system in accordance with Subsection I.2.7, Defect Reporting and Resolution.

7. Control the use of software in accordance with Subsection I.2.8, Control of the Use of Software.

C. Software, including macros, that can be verified by visual inspection and/or hand calculations shall have limited requirements applied as follows:

1. Listing of the baseline version and any subsequent changes to the software.

2. Documentation that the software provides correct results for a specified range of input parameters.

I.2.2 Software Verification and Software Validation

A. Software verification and software validation shall be performed prior to release. In those cases where this requirement cannot be met prior to the release of the software, the portions of software that have not been verified and validated shall be identified and controlled, and written justification of the reason documented.

B. Software verification and software validation activities shall be performed or reviewed by independent individuals or organizations who did not work on the original software development or modification. The person who directed the work may perform these activities with a higher level of management approval and documented justification.

I.2.3 Software Verification

A. The software verification shall be performed and documented to ensure that baseline elements meet the established requirements.

B. The verification documentation shall include a description of the tasks, methods, implementing documents, and acceptance criteria for accomplishing the software verification.

C. A record of the results of the execution of planned software verification shall be generated including the extent to which the results agree with the specified acceptance criteria.

1.2.4 Software Validation

A. Software validation activities (such as the development of test plans and test cases) shall be integrated into the software life cycle.

B. Testing shall be the primary method of software validation.

C. Software validation of modifications to released software items shall include regression testing.

D. Software validation shall be performed to an approved plan or process.

E. The test methods and test cases shall be documented to ensure that software meets the Affected Organization's requirements for its intended use.

F. The validation documentation shall include a description of the tasks, methods, implementing documents, and acceptance criteria for accomplishing the software validation.

G. A record of the results of the execution of planned software validation shall be generated including the extent to which the results agree with the specified acceptance criteria.

1.2.5 Documentation

Software activities shall be documented sufficiently to demonstrate the ability of the software to meet the needs of the Affected Organization and shall include the following:

A. Functional Requirements Information:

1. A description of the overall nature and purpose of the software.

2. Requirements for its intended use.

B. User Information:

1. A description of how to use the software item including:

a. Input and output options.

b. Data files, input and output data, defaults, and file formats.

c. A description of the allowable and tolerable ranges for inputs and outputs.

d. Anticipated errors and how the user can respond.

e. The hardware and software environments.

2. Available sample problems.

3. Installation procedures.

C. Requirements and Design Information:

1. Performance requirements and design constraints.

2. Interfaces with external data, hardware, or other software.

3. Applicable software and hardware operation issues including programming languages and versions, portability, maintainability, reliability, and efficiency.

4. A description of each software item as it relates to the functional requirements.

5. A description of the software structure including software internal interfaces, control logic, and data structure and flow.

6. A description of models and numerical methods.

7. Source code for developed software or software modification.

I.2.6 Software Configuration Management

A software configuration management system shall be established to include configuration identification and configuration control and status accounting. Software shall be placed under configuration management control as each baseline element is approved.

A. Configuration identification shall include:

1. A definition of the baseline elements of each software baseline.

2. A unique identification of each software item to be placed under software configuration management.

a. Each version or revision of a software item shall be uniquely identified and labeled.

b. The software version or revision identifier shall be included with the generated output, when feasible.

3. Assignment of unique identifiers that relate baseline documents to their associated software items. Cross-references between baseline documents and associated software shall be maintained.

B. Configuration control shall include:

1. A release and control process for baseline elements.

2. Changes to baseline elements, including retirement and withdrawal, shall be formally controlled and documented. This documentation shall contain a description of the change, the rationale for the change, and the identification of affected baseline elements.

   a. The change shall be formally evaluated and approved by the organization responsible for approving the baseline element.

   b. Only approved changes shall be made to software baselines.

   c. Information concerning approved changes shall be transmitted to all organizations affected by the changes.

   d. Software verifications shall be performed for the changes as necessary to ensure the changes are appropriately reflected in software documentation and to ensure that document traceability is maintained.

   e. Software validation shall be performed as necessary for the change.

C. Configuration status accounting shall include:

1. A listing of the approved baseline elements and unique identifiers.

2. The status of proposed and approved changes to the baseline elements.

3. A brief chronology of the software items, including descriptions of the changes made between versions of software items.

1.2.7 Defect Reporting and Resolution

A software defect reporting and resolution system shall be implemented.

A. The defect reporting and resolution system shall be integrated with the software configuration management system to ensure formal processing of defect resolutions.

B. Software defect reporting and resolution systems shall include the following controls:

1. Defects shall be documented and resolved.

2. Defects shall be assessed for their impact on previous applications.

3. Resolutions shall be reviewed and approved before changes are made to baseline elements.

4. Notification of identified user organizations.

C. If a defect is identified in software that adversely impacts previous applications, then the condition adverse to quality shall be documented and controlled in accordance with Section 16.0, Corrective Action.

I.2.8 Control of the Use of Software

A. Affected Organizations shall control and document the use of released software items such that comparable results can be obtained, with any differences explained, through independent replication of the process.

B. Use of software shall be independently reviewed and approved to ensure that the software selected is suitable to the problem being solved.

C. If use of a software item falls outside the range of validation, further validation shall be performed prior to use.

I.1 GENERAL

This supplement establishes requirements for the development, modification, control, and use of software. Software that is acquired as an integral part of measuring and test equipment, and has not been developed or modified by the Affected Organization, is controlled by Section 12.0, Control of Measuring and Test Equipment, and is exempt from the requirements of this supplement. Requirements for electronic management of data are addressed in Supplement V, Control of the Electronic Management of Data.

The following types of software are not required to be qualified using this supplement: operating systems; administrative and management systems; system utilities and compilers and their associated libraries; and word processing programs. Industry standard software such as database managers, graphing and visual display software, spreadsheets, and statistical software are also excluded. However, software routines and macros written for use within these types of industry standard software need to meet the requirements of Paragraph I.2.1.C.

I.2 REQUIREMENTS

I.2.1 Software Life Cycles, Baselines, and Controls

A. For developed or modified software, each Affected Organization shall document and approve a specific software life cycle for each software item prior to development or modification of software.

1. Software life cycles shall be defined by control points at which software baseline elements shall be documented. Software life cycle activities may be performed in an iterative or sequential manner.

2. When the software life cycle is defined for software development or modification within an Affected Organization, the documentation requirements of Subsections I.2.3, Software Verification, B and C, I.2.4, Software Validation, F and G, and I.2.5, Documentation, A, B, and C shall be established. All other requirements apply subsequent to establishment of the software life cycle.

3. Reviews of software baselines shall be performed and documented at the software control points.

B. For acquired software the following requirements shall be met:

1. Perform installation tests to ensure that software performs as required in the operational environment.

2. Perform validation in accordance with Subsection I.2.4, Software Validation, D, E, F, and G using test cases developed independently of the software developer. Additional test cases provided by the developer may be used to supplement this process with justification for their use.

3. Document in accordance with the requirements of Subsection I.2.5, Documentation, A, B, C.2, and C.6 as applicable.

4. Perform and document reviews of software baselines.

5. Place under the configuration controls in accordance with Subsection I.2.6, Software Configuration Management.

6. Implement a defect reporting and resolution system in accordance with Subsection I.2.7, Defect Reporting and Resolution.

7. Control the use of software in accordance with Subsection I.2.8, Control of the Use of Software.

C. Software, including macros, that can be verified by visual inspection and/or hand calculations shall have limited requirements applied as follows:

1. Listing of the version and any subsequent changes to the software.

2. Documentation that the software provides correct results for a specified range of input parameters.

I.2.2 Software Verification and Software Validation

A. Software verification and software validation shall be performed prior to release. In those cases where this requirement cannot be met prior to the release of the software, the portions of software that have not been verified and validated shall be identified and controlled, and written justification of the reason documented.

B. Software verification and software validation activities shall be performed or reviewed by independent individuals or organizations who did not work on the original software development or modification. The person who directed the work may perform these activities with a higher level of management approval and documented justification.

1.2.3 Software Verification

A. The software verification shall be performed and documented to ensure that baseline elements meet the established requirements.

B. The verification documentation shall include a description of the tasks, methods, implementing documents, and acceptance criteria for accomplishing the software verification.

C. A record of the results of the execution of planned software verification shall be generated including the extent to which the results agree with the specified acceptance criteria.

1.2.4 Software Validation

A. Software validation activities (such as the development of test plans and test cases) shall be integrated into the software life cycle.

B. Testing shall be the primary method of software validation.

C. Software validation of modifications to released software items shall include regression testing.

D. Software validation shall be performed to an approved plan or process.

E. The test methods and test cases shall be documented to ensure that software meets the Affected Organization's requirements for its intended use.

F. The validation documentation shall include a description of the tasks, methods, implementing documents, and acceptance criteria for accomplishing the software validation.

G. A record of the results of the execution of planned software validation shall be generated including the extent to which the results agree with the specified acceptance criteria.

1.2.5 Documentation

Software activities shall be documented sufficiently to demonstrate the ability of the software to meet the needs of the Affected Organization and shall include the following:

A. Functional Requirements Information:

1. A description of the overall nature and purpose of the software.

2. Requirements for its intended use.

B. User Information:

1. A description of how to use the software item including:

a. Input and output options.

b. Data files, input and output data, defaults, and file formats.

c. A description of the allowable and tolerable ranges for inputs and outputs.

d. Anticipated errors and how the user can respond.

e. The hardware and software environments.

2. Available sample problems.

3. Installation procedures.

C. Requirements and Design Information:

1. Performance requirements and design constraints.

2. Interfaces with external data, hardware, or other software.

3. Applicable software and hardware operation issues including programming languages and versions, portability, maintainability, reliability, and efficiency.

4. A description of each software item as it relates to the functional requirements.

5. A description of the software structure including software internal interfaces, control logic, and data structure and flow.

6. A description of models and numerical methods.

7. Source code for developed software or software modification.

1.2.6 Software Configuration Management

A software configuration management system shall be established to include configuration identification and configuration control and status accounting. Software shall be placed under configuration management control as each baseline element is approved.

A. Configuration identification shall include:

1. A definition of the baseline elements of each software baseline.

2. A unique identification of each software item to be placed under software configuration management.

a. Each version or revision of a software item shall be uniquely identified and labeled.

b. The software version or revision identifier shall be included with the generated output, when feasible.

3. Assignment of unique identifiers that relate baseline documents to their associated software items. Cross-references between baseline documents and associated software shall be maintained.

B. Configuration control shall include:

1. A release and control process for baseline elements.

2. Changes to baseline elements, including retirement and withdrawal, shall be formally controlled and documented. This documentation shall contain a description of the change, the rationale for the change, and the identification of affected baseline elements.

   a. The change shall be formally evaluated and approved by the organization responsible for approving the baseline element.

   b. Only approved changes shall be made to software baselines.

   c. Information concerning approved changes shall be transmitted to all organizations affected by the changes.

   d. Software verifications shall be performed for the changes as necessary to ensure the changes are appropriately reflected in software documentation and to ensure that document traceability is maintained.

   e. Software validation shall be performed as necessary for the change.

C. Configuration status accounting shall include:

1. A listing of the approved baseline elements and unique identifiers.

2. The status of proposed and approved changes to the baseline elements.

3. A brief chronology of the software items, including descriptions of the changes made between versions of software items.

I.2.7 Defect Reporting and Resolution

A software defect reporting and resolution system shall be implemented.

A. The defect reporting and resolution system shall be integrated with the software configuration management system to ensure formal processing of defect resolutions.

B. Software defect reporting and resolution systems shall include the following controls:

1. Defects shall be documented and resolved.

2. Defects shall be assessed for their impact on previous applications.

3. Resolutions shall be reviewed and approved before changes are made to baseline elements.

4. Notification of identified user organizations.

C. If a defect is identified in software that adversely impacts previous applications, then the condition adverse to quality shall be documented and controlled in accordance with Section 16.0, Corrective Action.

1.2.8 Control of the Use of Software

A. Affected Organizations shall control and document the use of released software items such that comparable results can be obtained, with any differences explained, through independent replication of the process.

B. Use of software shall be independently reviewed and approved to ensure that the software selected is suitable to the problem being solved.

C. If use of a software item falls outside the range of validation, further validation shall be performed prior to use.

SUPPLEMENT I SOFTWARE

I.1 GENERAL

This supplement establishes requirements for the acquisition, development, modification, control, and use of software. Acquired software that is integral to the operations, maintenance, or calibration of measuring and test equipment, and has not been developed or modified by the Affected Organization, is controlled by Section 12.0, Control of Measuring and Test Equipment, and is exempt from the requirements of this supplement. Requirements for electronic management of data are addressed in Supplement V, Control of the Electronic Management of Data.

The following types of software are not required to be qualified using this supplement: operating systems; system utilities; compilers and their associated libraries; word processors; spreadsheets; database managers; e-mail; and other types of automated office support systems. Any applications, other than software routines and macros, developed using these types of commercially available software shall meet the requirements of this supplement. Software routines and macros shall meet the requirements of Paragraph I.2.1.C.

I.2 REQUIREMENTS

I.2.1 General Software Requirements

A. Software acquisition, development, modification, and maintenance shall proceed in a planned, traceable, and orderly manner utilizing a defined software life cycle methodology.

1. A defined software life cycle methodology shall address the following phases: requirements, design, implementation, testing, installation and checkout, operations and maintenance, and retirement. The number of phases and relative emphasis placed on each phase of the software life cycle will depend on the nature and complexity of the software. Software life cycle activities may be performed in an iterative or sequential manner.

2. Acquired software or software previously developed not using this supplement must either be: a) acquired through a procurement activity in accordance with Section I.2.6 with appropriate quality controls, or b) be controlled and qualified in accordance with Section I.2.7 of this supplement. In either case, software planning in accordance with I.2.2 and a defined software life cycle methodology, excluding a design document and code development, shall be applied.

3. Software life cycles shall contain control points that, when reached, shall ensure specified software is documented, reviewed, and baselined.

B. Software verification and validation activities shall be planned, documented, and performed for each software, for software changes, or for those system configurations that are determined to impact the software.

1. Software verification shall be performed at the end of the Requirements, Design, Implementation, and Testing life cycle phases to ensure that the products of a given life cycle phase are traceable and fulfill the requirements of the previous phase and/or previous phases.

2. Verification reviews shall identify the reviewer(s) and their specific responsibilities during the review.

3. Software verification and validation activities shall be performed by individuals not associated with the development of the software. In those instances where this level of independence may not be achieved, an individual associated with the development of the software may perform these activities with a higher level of management approval and documented justification.

C. Software routines or macros that are documented in each product in which they are used and independently verified by visual inspection or hand calculation without recourse to the originator shall have limited requirements applied as follows:

1. Identification, including version of the software routine or macro.

2. Documentation that includes inputs, computer program generated correct results for a specified range of input parameters, computer program generated evidence of the programmed algorithms or equations (e.g., computer programs listings and spreadsheet cell contents), and verification results.

3. Identification, including version of the commercially available software used to develop the routine and macro.

I.2.2 Software Planning

A. A plan addressing software quality assurance (QA) shall be in existence for each new software project at the start of the software life cycle.

B. The plan(s) may be prepared individually for each software project, or may exist as a generic document to be applied to software prepared within or procured by an organization, or may be incorporated into the overall QA program.

C. The plan for software shall identify:

1. A description of the overall nature and purpose of the software.

2. The software products to which it applies.

3. The organizations responsible for performing the work and achieving software quality and their tasks and responsibilities.

4. Required documentation.

5. Standards, conventions, techniques, or methodologies that shall guide the software activity.

6. Required software reviews.

7. Methods for error reporting and corrective action.

1.2.3 Software Life Cycle Requirements

A. Requirement Phase

1. Software requirements that address functionality, performance, design constraints, attributes, and external interfaces shall be specified, documented, and reviewed.

   a. Functionality–The functions the software is to perform.

   b. Performance–The time-related issues of software operation such as speed, recovery time, response time, etc.

   c. Design constraints imposed on implementation phase activities–Any elements that will restrict design options.

   d. Attributes–Non-time-related issues of software operation such as portability, acceptance criteria, access control, maintainability, etc.

   e. External interfaces–Interactions with people, hardware, and other software.

2. A software requirement shall only be specified if its achievement can be verified and validated.

3. Software requirements shall be traceable throughout the remaining stages of the software life cycle.

4. Software requirements shall provide enough detail to either design the software or make an acquisition decision.

B. Design Phase

1. The software design shall be developed, documented, and reviewed based on the requirements depicted in the requirements document.

2. The design documentation shall specify:

   a. A description of the major components of the software design as they relate to the software requirements.

   b. A technical description of the software with respect to the theoretical basis, mathematical model, control flow, data flow, control logic, and data structure.

   c. A description of the allowable or defined ranges for inputs and outputs.

   d. The design described in a manner that can be translated into code.

   e. The generation of design-based test cases.

   f. The generation of test plans/cases, based on the requirements and design, shall provide for acceptance criteria and verification of results. Alternative methods to evaluate technical adequacy may be used, such as:

      1) Analysis without computer assistance (hand calculations).
      2) Other validated computer programs.
      3) Experiments and tests.
      4) Standard problems with known solutions.
      5) Comparisons to confirmed published data correlations.

C. Implementation Phase

1. The design shall be translated into source code and resulting executables necessary to perform the functions required.

2. The source code and resulting executables shall adhere to the design specifications.

3. User information shall be developed, documented, and reviewed in accordance with the design to delineate how to use the software, including the following, as applicable:

   a. Instructions that contain an introduction (e.g., purpose, scope, etc.), description of the user's interaction with the software, and a description of any required training necessary to use the software.

   b. Input and output specifications.

   c. Data files, input and output data, defaults, and file formats.

   d. A description of the allowable and tolerable ranges for inputs and outputs.

e. Anticipated errors and how the user can respond.

f. The hardware and software environments.

g. Available sample problems.

h. Installation procedures.

D. Testing Phase

1. Software validation activities shall be performed, documented, and verified at the end of the implementation phase to ensure that the software installs properly and satisfies the requirements for its intended use.

2. Testing, to an approved plan or process, shall be the primary method of software validation to ensure adherence to the requirements, and to ensure that the software produces correct results for the test cases.

3. Software validation documentation shall describe the task and criteria for accomplishing the validation of the software at the end of the development cycle. The documentation shall:

   a. Specify the hardware and software configurations.

   b. Be organized in a manner that allows traceability to both software requirements and design.

   c. Contain the results of the execution of the validation activity.

   d. Include the results of reviews and tests along with a summary of the status of the software (e.g., indication of incomplete design performance and application requirements).

4. Failure to successfully execute the test cases shall be documented and reviewed to determine if modifications to the requirements, design, implementation, or test plans and cases are required.

5. Software validation of modifications to released software shall be subjected to regression testing to detect errors introduced during the modification of the software, to verify that the modifications have not caused unintended adverse affects, or to verify that a modified software still meets specified requirements.

E. Operations and Maintenance Phase

1. Upon acceptable validation of the software, in accordance with I.2.3.D, the software shall be baselined and placed under Configuration Management controls in accordance with section I.2.4.

2. Further operations and maintenance activities shall consist of maintenance of the software:

   a. To remove latent errors (corrective maintenance).

   b. To respond to new or revised requirements (perfective maintenance).

   c. To adapt the software to changes in the operating environment (adaptive maintenance).

3. Software modifications shall be approved, documented, verified and validated, and controlled.

4. In-use tests shall be developed, performed, documented, and verified to provide confirmation of acceptable performance of software that is performing continuous data acquisition or process control functions. Periodic manual or automatic self-check in-use tests shall be defined and performed for those software where computer program errors, data errors, computer hardware failures, or instrument drift can affect the required performance.

F. Installation and Checkout Phase

1. Software installation and checkout activities shall be performed and documented when the software is installed on a computer, or when there are changes in the operating system, to ensure that the software installs properly and satisfies the requirements for its intended use.

2. The software validation activities for the installation and checkout shall consist of:

   a. The execution of tests for installation.

   b. The documentation that the software was successfully installed and ready for operational use.

G. Retirement Phase

During the retirement phase, the support for a software product is terminated and use of the software shall be prevented.

1.2.4 Software Configuration Management

A software configuration management system shall be established to include configuration identification, configuration change control, and status accounting. Software shall be placed under configuration management control as each baseline element is approved. Software shall not be used in activities identified under Section 2.2.2 or 2.2.3 of this document unless it is obtained, and limited to received copies, from software configuration management.

A. Configuration identification shall include:

1. A definition of the baseline elements of each software baseline.

2. A unique identification of each software item, including version or revision, to be placed under software configuration management.

3. Assignment of unique identifiers that relate baseline documents to their associated software items. Cross-references between baseline documents and associated software shall be maintained.

B. Configuration change control shall include:

1. A release and control process for baseline elements.

2. Changes to baseline elements shall be formally controlled and documented. This documentation shall contain a description of the change, the rationale for the change, and the identification of affected baseline elements.

3. A formal evaluation of the baseline element or change to the baseline element and approval by the organization responsible for approving the baseline element.

4. The transmission of information concerning approved changes to all organizations affected by the changes.

5. Software verifications performed for the changes as necessary to ensure the changes are appropriately reflected in software documentation and to ensure that document traceability is maintained.

6. Software validation performed as necessary for the change.

C. Configuration status accounting shall include:

1. A listing of the approved baseline elements and unique identifiers.

2. The status of proposed, in-process, or approved changes to the baseline elements.

3. A history of changes to the software items, including descriptions of the changes made between versions of software items.

1.2.5 Defect Reporting and Resolution

A. A software defect reporting and resolution system shall be implemented for software errors and failures to assure that problems are promptly reported to Affected Organizations and to assure formal processing of problem resolutions.

B. The defect reporting and resolution system shall be integrated with the software configuration management system.

C. Software defect reporting and resolution systems shall include the following controls:

1. Problems are identified, evaluated, documented, and, if required, corrected.

2. Problems are assessed for impact on past and present applications of the software by the responsible organization.

3. Corrections and changes shall be controlled in accordance with applicable configuration change control requirements.

4. Notification along with preventive actions and corrective actions are provided to the user organizations.

D. If a defect is identified in software that adversely impacts previous applications, then the condition adverse to quality shall be documented and controlled in accordance with Section 16.0, Corrective Action.

1.2.6 Software Procurement

A. Individuals or organizations developing and supplying software under contract shall be required to have policies and procedures that meet the applicable requirements of this Supplement as specified in procurement documents.

1. Documentation as required by this Supplement shall be delivered or made available by the supplier to the purchaser.

2. Upon receipt of the software from the supplier, the purchaser assumes responsibility of the applicable requirements as specified in this supplement.

3. Software errors and failures shall be reported between the supplier and purchaser in accordance with I.2.5.

B. For procured software services, the organization providing the services shall have plan(s) for software QA, in accordance with I.2.2.A, that meets the requirements of I.2.6.A, and the user organization shall determine the adequacy of this plan.

I.2.7 Software Previously Developed Not Using This Supplement

This section shall apply only to unqualified software in which the history of the software is not known, but the software is required to be used in quality affecting activities.

A. Software that was previously developed not using this supplement shall be placed under configuration controls prior to use.

B. The user organization shall perform, document, and provide for an independent review and evaluation to:

1. Determine its adequacy to support software operation and maintenance.

2. Identify the activities to be performed and documents required in order for the software to be placed under configuration management. As a minimum, these activities shall include:

a. User application requirements.
b. Test plans and test cases required to validate the software for acceptability.
c. User documentation required in accordance with I.2.3.C.3.

C. Upon independent review and approval of the above activities, the software shall be placed under configuration control in accordance with I.2.4.

I.2.8 Control of the Use of Software

A. Affected Organizations shall control and document the use of released software items such that comparable results can be obtained, with any differences explained, through independent replication of the process.

B. Use of software shall be independently reviewed and approved to ensure that the software selected is suitable to the problem being solved.

C. If the intended use of a software item falls outside the range of validation as baselined, changes shall be made to the appropriate baseline elements prior to continuing use.

D. Documentation for the receipt of software obtained from Software Configuration Management in accordance with Section I.2.4 shall be provided and maintained for all software in operation or use.

ENCLOSURE

#6

SECTION 1

House Government Reform Committee

Federal Workforce and Agency Organization
Subcommittee Hearing

References:
Infiltration Modeling at Yucca Mountain

June 29, 2005

Table 6-9. Estimation Results for Present-Day Climate Scenarios Over the 38.7- km^2 Area of the 1999 UZ Flow Model Domain

		Estimation Results for Present-Day Climate Scenarios for Area of 1999 UZ Flow Model Domain		
Present-day climate scenario		Lower bound	Mean	Upper bound
Filename for spatial distribution results		*Modernl.dat*	*Modernm.dat*	*Modernu.dat*
Average annual precipitation (mm/year)	Mean	186.8	190.6	268.6
	Maximum	246.3	246.5	347.4
	Minimum	162.7	167.1	235.5
Average annual evapotranspiration (mm/year)	Mean	186.2	185.3	257.1
	Maximum	367.9	348.2	485.6
	Minimum	62.2	59.7	77.2
Average annual infiltrated surface water run-on (mm/year)	Mean	1.9	4.1	10.1
	Maximum	194.9	277.0	802.9
	Minimum	0.0	0.0	0.0
Average annual outflow (mm/year)		-0.7	-0.2	-0.3
Average annual net infiltration (mm/year)	Mean	1.3	4.6	11.1
	Maximum	218.8	263.6	784.9
	Minimum	0.0	0.0	0.0

Output DTN: GS000308311221.005.

NOTE: Estimates of net infiltration for the UZ flow model area differ slightly from those reported in BSC (2004 [DIRS 169861], Table 6.1-2) because the 1999 UZ flow model boundary for site recommendation is used in this report while the 2003 UZ flow model boundary for license application is used in BSC (2004 [DIRS 169861]).

Table 6-10. Estimation Results for Present-Day Climate Scenarios Over the 4.7- km^2 Area of the 1999 Repository Footprint

		Estimation Results for Present-Day Climate Scenarios for Area of Repository		
Present-day climate scenario		Lower bound	Mean	Upper bound
Filename for spatial distribution results		*Modernl.dat*	*Modernm.dat*	*Modernu.dat*
Average annual precipitation (mm/year)	Mean	191.6	196.9	277.5
	Maximum	204.1	209.9	295.8
	Minimum	178.2	183.4	258.5
Average annual evapotranspiration (mm/year)	Mean	191.7	189.9	260.4
	Maximum	252.9	273.3	423.0
	Minimum	155.0	154.7	203.0
Average annual infiltrated surface water run-on (mm/year)	Mean	1.0	3.4	8.1
	Maximum	59.8	161.1	454.8
	Minimum	0.0	0.0	0.0
Average annual outflow (mm/year)		-0.3	1.4	4.9
Average annual net infiltration (mm/year)	Mean	0.4	4.7	11.6
	Maximum	26.6	120.1	387.4
	Minimum	0.0	0.0	0.0

Output DTN: GS000308311221.005.

ENCLOSURE

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SECTION 2

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STATE OF NEVADA
OFFICE OF THE STATE ENGINEER

WATER RESOURCES BULLETIN No. 8

GROUND WATER IN WHITE RIVER VALLEY, WHITE PINE, NYE, AND LINCOLN COUNTIES, NEVADA

By
G. B. MAXEY and T. E. EAKIN

Prepared in cooperation with the
UNITED STATES DEPARTMENT OF THE INTERIOR
Geological Survey
1949

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FOREWORD

This report is the eighth in the series of Nevada Water Resources Bulletins prepared by the U. S. Geological Survey, in cooperation with the Office of the State Engineer.

Ground-water investigations on a State-wide basis were begun July 1, 1945 as the result of increasing interest in the development of additional water supplies in Nevada. The development of additional water in the State must come, to a considerable extent, from ground-water resources because surface water has been almost entirely appropriated.

The reports resulting from these investigations form a basis for the proper understanding of the occurrence, source, movement, and disposal of ground water in the ground-water reservoirs in the State. They also include estimates for the amount of water that may be potentially developed from the ground-water reservoirs. Such information is necessary for the conservation of our ground-water resources and at the same time permits full and intelligent development of the potential water available. Under natural conditions, much ground water is used to support native phreatophyte vegetation (plants that depend upon ground water to supply their needs), and in evaporation from soil and from free-water surfaces. The water so lost may be salvaged in part by withdrawals from wells and thereby be utilized for higher beneficial use.

The cooperative program is under the supervision of Hugh A. Shamberger, Assistant State Engineer of Nevada, and Thomas W. Robinson, District Engineer, Ground Water Branch, U. S. Geological Survey.

ALFRED MERRITT SMITH,
State Engineer.

November 14, 1949.

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ABSTRACT

White River Valley, in east-central Nevada, is a semiarid intermontane trough in the central part of the Great Basin, at the upper end of a long, narrow tongue of the Colorado River drainage basin. The sparse population is principally engaged in agriculture. The water supply is derived from large springs which annually discharge about 40,000 acre-feet of water and from White River, which annually discharges about 2,000 acre-feet. The only two irrigation wells in the valley were pumped to supplement the surface-water supply in 1947. Nearly 4,200 acres of land are now irrigated. The main purpose of this investigation was to obtain an estimate of the amount of ground water in the valley available for irrigation.

The principal water-bearing beds are in the alluvial apron and river-bed deposits which underlie the valley lowland. These aquifers consist of moderately to highly permeable sand and gravel deposits interbedded with silt and clay. The igneous and sedimentary bedrocks of the mountains that surround the valley are relatively impermeable and are a barrier to movement of ground water, except for parts of the Pogonip and Nevada limestones of Paleozoic age. These limestones are cavernous and are believed to transmit large quantities of water. Water issuing from Preston Big Springs and Lund, Hot Creek, and some other large springs is probably supplied from these limestones. Some water transmitted from the mountainous recharge areas by these limestone aquifers may also recharge the ground-water reservoir of the valley fill.

The ultimate source of the ground water is from precipitation within the watersheds of White River and Jakes Valleys. Most of the precipitation is lost by evaporation and transpiration before it percolates into the ground-water reservoir. Estimates based on the available precipitation data, and on studies of recharge in somewhat comparable areas, indicate that the annual ground-water recharge is about 53,000 acre-feet. This water moves underground toward the axis of the valley where about 34,000 acre-feet is discharged from the valley by evapo-transpiration. The remainder flows out of the valley on the surface or as underflow.

GROUND WATER IN WHITE RIVER VALLEY, IN WHITE PINE, NYE, AND LINCOLN COUNTIES, NEVADA

By G. B. Maxey and T. E. Eakin

INTRODUCTION

White River Valley lies in the southwest part of White Pine County, the northeast part of Nye County, and the northwest corner of Lincoln County, in east-central Nevada (see fig. 1). Preston and Lund, the principal communities in the valley, are centers for farming and stock-raising activities, the only important industries in the valley. These towns are about 35 miles southwest of Ely, the county seat of White Pine County. They are reached from Ely by U. S. Highway 6, which cuts southwest across the north end of the valley, and by Nevada State Highway 38, which traverses the valley from its intersection with U. S. Highway 6 southward through Preston and Lund. Nevada State Highway 38A connects Lund with Hiko to the south in Lincoln County. The population of the valley in 1940 was about 850 and was believed to be about the same in 1948.

The principal water supply for White River Valley is obtained from several large springs, and from White River, Water Creek, and Ellison Creek, the only perennial streams. Water from these sources has been sufficient to irrigate the cultivated land in the valley since it was first settled in the early 1860's, except during periods of drought. Many wells have been drilled since about 1925 to obtain water for stock and domestic use. Also, a few irrigation wells, of which two were used during 1947, have been drilled during the last 10 years to supplement irrigation supplies from the springs and streams. All the arable land in the valley is not being cultivated, and further farming activity depends in part upon utilization of the ground water that may be developed by wells.

The feasibility of developing ground water by wells for irrigation has long been discussed by residents in the valley and by county, State, and Federal officials, but detailed studies of the ground-water conditions have never been made. The U. S.

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On the basis of the amount of ground water now lost by transpiration and evaporation, the depth to the water table, and the water-bearing characteristics of the ground-water reservoir, it is estimated that about 19,000 acre-feet of water of suitable quality is annually available for irrigation by pumping. Also, 11,000 acre-feet of water discharged by Hot Creek Spring may be made available for irrigation by diverting the water, either by ditch or by low-lift pumping. Artificial recharge to the ground-water reservoir also may be feasible to conserve part of the winter discharge of the large springs, and it may be desirable if future development of pumping for irrigation materially lowers the water table in the vicinity of Preston and Lund. That artificial recharge can be accomplished effectively is demonstrated in part by substantial losses of water from ditches to the ground-water reservoir.

This report contains tables giving climatological data, available discharge records of springs and streams, analyses of the waters of three large springs, and records for most of the wells and the principal springs in the valley. Illustrations showing the drainage area, areal distribution and nature of the water-bearing formations, water-table contours, the extent of the recharge and transpiration areas, and the area of irrigated lands are also presented.

A reconnaissance report on land classification by Howard G. Mason, Nevada Agricultural Experiment Station, is included.

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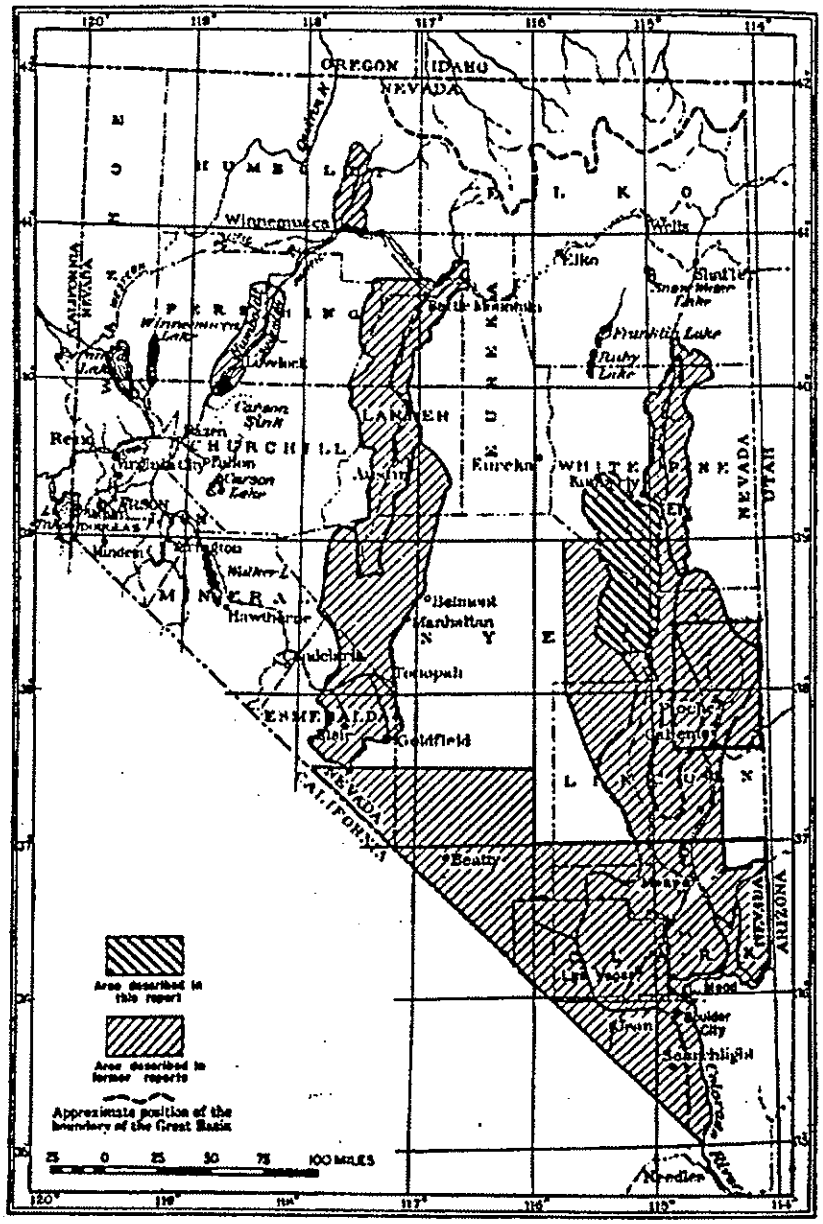

FIGURE 1—Map of Nevada showing areas covered by published ground-water reports and by the present report.

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Geological Survey,[1] White Pine County,[2] the Nevada State Agricultural Experiment Station,[3] the Bureau of Agricultural Economics of the U. S. Department of Agriculture,[4] and the Soil Conservation Service[5] made brief ground-water investigations in the valley prior to the present study. The reports of these investigations contain general information that was of considerable help to the present study and they have been consulted freely.

The purpose of the present investigation was to determine, by means of geologic and hydrologic studies, the source, movement, and quality of the ground water and the amount that could be developed by wells without exceeding the safe yield. In addition, this report begins the systematic collection of hydrologic data which may be used for evaluation of the ground-water resources from time to time as development progresses.

An inventory of 98 wells and 12 springs has been made since the study was started in July 1947. This inventory is shown in Tables 6, 7, 8, 9, and 10. All available well and spring records have been studied and the total discharge from wells and springs has been determined. Estimates were made of the discharge of ground water by evaporation and transpiration in areas where the water table is at or near the land surface, and of outflow from the valley. The quality and temperature of the ground water studied. A reconnaissance map showing the general geology of the valley was prepared and the relations between geologic and ground-water conditions studied. All available and reliable well logs have been compiled and are presented in Table 10. Water levels are being measured periodically in 12 selected observation wells.

The cooperation of the well owners in White River Valley in allowing their wells to be used for measurements and tests was invaluable to the investigation and is hereby acknowledged. Two local well drillers, Dennis Smith and J. D. Hill, kindly furnished numerous well logs and other data for wells that they have

[1]Carpenter, Everett, Ground water in southeastern Nevada: U. S. Geol. Survey Water-Supply Paper 365, 86 pp., 1915.

[2]Well data files, office of the County Clerk, White Pine County, Nevada, 1913–1948.

[3]Hardman, George, and Miller, M. R., The quality of the waters of southeastern Nevada, drainage basins and water resources: Univ. Nevada, Agr. Exper. Sta. Bull. 136, p. 37, 1934.

[4]Water facilities area plan for upper White River sub-area of the Virgin River area, Nevada: U. S. Dept. Agr., Bur. Agr. Econ., 57 pp., 1942.

[5]Better land use in the White Pine Soil Conservation District: U. S. Dept. Agr., Soil Cons. Service, pp. 26–30, 1943.

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drilled in the valley. The writers wish to thank William Helphinstine, White Pine County Agricultural Agent; the officials of White Pine County; the Soil Conservation Service; the Bureau of Land Management; the State Department of Highways, and the Office of the State Engineer, all of whom assisted by making available valuable data. F. W. Millard and Son, consulting engineers in Ely, Nevada, assisted by contributing data. Grateful appreciation is extended to the writers' colleagues on the Geological Survey who reviewed the report and offered much helpful criticism.

The investigation has been under the general supervision of T. W. Robinson, District Engineer in Nevada for the Ground Water Branch, U. S. Geological Survey.

LOCATION AND GENERAL FEATURES

White River Valley, as defined in this report, includes about 1,620 square miles of the White River drainage basin lying north of the line of low bedrock hills extending eastward from Troy Peak and about 8 miles south of the Adams-McGill reservoir. The valley, which is about 70 miles long and ranges in width from 20 to 30 miles, comprises the north part of the White River drainage area between 114°53′ and 115°27′ west longitude and between 38°15′ and 39°17′ north latitude (see pl. 1). That part of the White River drainage basin lying south of this area, locally referred to as White River Wash, is not included in the present investigation.

The valley is in the central part of the Great Basin section of the Basin and Range physiographic province. It is at the north end of a long tongue of the Colorado River drainage basin. Although it is not an enclosed basin with interior drainage, it possesses many of the features of the intermontane basins of the Great Basin section. It is an elongate lowland filled to an undetermined depth with unconsolidated deposits of gravel, sand, silt, and clay. The lowland is bounded by high, northerly trending, more or less parallel mountain ranges composed of well-indurated sedimentary and igneous rocks. The broad river channel which occupies the valley floor is physiographically analogous to the playa lakes usually found in the intermontane basins. An alluvial apron, consisting of coalescing alluvial fans which head in the canyons of the mountains, extends to the river channel. Thus the valley lowland consists of the river channel and the alluvial apron. As in the intermontane basins nearby,

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the boundary of this valley lowland is roughly the same as the contact between the alluvial apron and the bedrock of the mountainous areas.

The valley lies between the Egan Range on the east and a chain of mountain ranges consisting of the White Pine Mountains, the Horse Range, and the Grant Range on the west. The northern boundary of the valley is a range of low hills that extends southwest from Kimberly to a point about 4 miles northwest of Baldy Mountain and forms a topographic divide between White River and Jakes Valleys. The east side of the valley is nearly straight and trends almost due north. The west side of the valley is irregular, especially in the south part.

The valley lowland which is about 4 miles wide at the north end, just south of Dark Peak, gradually increases to a width of about 10 miles in the vicinity of Preston. From Preston south for a distance of 10 miles it ranges in width from 8 to 10 miles. A large reentrant on the west side of the valley, locally referred to as The Cove, extends west at this point toward the Horse Range. This broader segment of the valley is about 14 miles wide and continues southward about 8 miles, where spurs of the Grant and Egan Ranges extend toward the axis of the valley and reduce its width to about 8 miles. Southward from here the valley widens to more than 15 miles and then narrows to about 6 miles at the south boundary of the area. The floor of the valley lowland slopes southward from an altitude of about 6,000 feet, 8 miles north of Preston, to an altitude of about 5,100 feet at the south end. The valley lowland has been moderately dissected by White River and its tributaries. Excavation of the broad river channel with its marginal terraces cut in the sediments of the alluvial apron probably took place during the Pleistocene epoch, when the climate was more humid than at present. Carpenter[1] states "during the humid Pleistocene epoch * * * a stream of considerable magnitude carved a channel through the valley from Preston to the head of Muddy Valley." The Muddy Valley is tributary to the Colorado River.

The Egan Range is a persistently high mountain mass from 5 to 10 miles wide that extends north along the east side of the White River Valley from a point about 10 miles south of Sunnyside to Kimberly, a distance of about 65 miles. It reaches altitudes of about 8,500 feet east of Sunnyside, about 10,000 feet

[1]Carpenter, Everett, Ground water in southeastern Nevada: U. S. Geol. Survey Water-Supply Paper 365, p. 54. 1915.

9 0 0 4 2 0 4 0 5

east of Lund, and 10,929 feet at Ward South Summit, the highest peak near the north end of the range. Its crest is the main drainage divide between White River Valley and Steptoe and Cave Valleys. The range is lower south of Sunnyside and is separated by low passes from some low unnamed mountains which are the northward extension of the Pahroc Range.

A low ridge of unnamed hills extends across the north end of the valley from Kimberly southwesterly toward Baldy Mountain, thus connecting the Egan Range and the White Pine Mountains. These hills form a topographic divide between White River and Jakes Valleys and reach altitudes ranging from about 6,800 to 8,000 feet.

The White Pine Mountains bound the northwest part of White River Valley. They extend north from U. S. Highway 6 at Currant Summit beyond the north end of the valley, where they bound Jakes Valley on the west. This range is the highest in the vicinity of White River Valley. The highest peak, Currant Mountain, reaches an altitude of 11,493 feet. The altitude exceeds 9,000 feet throughout most of the length of the range. The White Pine Mountains are drained by White River and its tributary, Ellison Creek, both perennial streams.

The Horse Range reaches an altitude of 8,000 feet but averages considerably lower. It extends south about 10 miles from Currant Summit along the west side of White River Valley to the north end of the Grant Range.

The Grant Range extends south from the Horse Range beyond the south border of the valley. The north end of the range is low, with an average altitude of about 7,500 feet. The main part of the range rises southward and near the south end it reaches 11,268 feet above sea level at Troy Peak.

DRAINAGE

White River Valley is drained by White River and its tributaries. The river and its principal tributary, Ellison Creek, head in the White Pine Mountains. They converge near U. S. Highway 6 at the Rosevear Ranch, where the river crosses the contact of the bedrock and the valley fill and enters the valley lowland. During the summer water flows in the river channel as far south as Lund before it is entirely depleted by irrigation diversions and by evaporation and infiltration. During the winter months water usually flows to a point about 15 miles south of the Adams-McGill reservoir, about 50 miles south of Lund, where it sinks into the old river bed.

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White River and Ellison Creek were measured just above their confluence near U. S. Highway 6 during the period of low flow on December 22, 1947. The discharge of the river was 1.66 second-feet and that of Ellison Creek was 0.43 second-foot, making the total discharge below the confluence 2.09 second-feet. Measurements of these streams have been made from time to time by the State Engineer's office since 1908. During 1914 a gaging station was maintained on White River, above Preston, by the U. S. Geological Survey from late May until early September. All these measurements are shown in Table 1.

As shown by the table, the maximum measured discharge of White River below its confluence with Ellison Creek was 44 second-feet in 1914 and, the minimum was 1.85 on September 10, 1937. It is reported that the river has discharged as much as 75 second-feet during the spring runoff period. Most of the water in White River is used for irrigation by farmers in the area adjacent to U. S. Highway 6. The maximum flow reaching the valley lowland near Preston during the irrigation season is about 4 second-feet and the average flow is about 2 second-feet.

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TABLE 1

Discharge of White River, White Pine County, Nevada[1]

Data from water-supply card of State Engineer of Nevada

Point of measurement for the following five measurements unknown, but believed to be between McQuean Ranch and Rosevear Ranch.

Date	Place	Discharge (sec.-ft.)
August 1908	3 miles below spring	9.0
September 1908	At spring	2.8
June 1908	At spring	7.0
June 1908	4 miles downstream from spring	8.5
May 7, 1913	300 feet west of school and below most diversions	.80

Data from U. S. Geological Survey, Water Resources Division

Location—Approximately in sec. 4, T. 12 N., R. 61 E., M.D.M., 250 feet above the north- and south-side dividing flume, about 3 miles northwest of Preston. Staff gage was installed in 1913 at Preston, above all diversions for the district, but there are several small diversions for ranches in the neighborhood of Barnes. Observations discontinued September 4, 1914. Measurements in second-feet.

1914	May	June	July	Aug.	Sept.
1	...	14	5	1.0	0.3
2	....	17	4	1.0	.4
3	...	17	3.5	.9	.7
4	...	17	4	1.1	Dry
5	...	17	4	1.3	
6	....	18	4.5	1.5	
7	.	19	4	1.7	
8	....	18	4	1.9	
9	....	18	4	.9	
10	....	17	5	1.1	
11	....	16	5.5	1.3	
12	....	15	4	1.5	
13	....	14	4.5	1.9	
14	....	13	4.0	2.3	
15	...	13	3.5	1.9	
16	...	13	2.7	1.5	
17	...	12	2.4	1.5	
18	....	11	3	1.5	
19	...	7	2	1.5	
20	..	7	1.4	1.5	
21	...	7	1.7	1.2	
22	...	7	2.0	.9	
23	....	7	2.3	.8	
24	...	7	2.3	.7	
25	...	15	2.4	.4	
26	...	24	2.4	.2	
27	12	10	2.4	.2	
28	11	5.5	4	.2	
29	11	6	14	.2	
30	11	6	4	.2	
31	12	...	3.4	.2	

Data from water-supply card of State Engineer of Nevada

Date	Place	Discharge (sec.-ft.)
Oct. 16, 1914	300 feet west of school and below most diversions	0.7
July 3, 1915	Midland Trail Bridge at McQuean Ranch	3.6
June 24, 1916	Above gaging station	4.2
May 27, 1918	At bridge on Midland Trail	3.34

Data from Water Commissioner Reports to State Engineer of Nevada
(Unless stated, point of measurement is unknown)

Date	Place	Discharge (sec.-ft.)
May 18, 1924		6.74
May 20		6.21
May 21		6.21
June 3		5.35

[1]Data compiled by F. N. Dondero, Office Engineer, Office of the State Engineer of Nevada, from records of the Office of the State Engineer of Nevada, and from publications of the U. S. Geological Survey, Water Resources Division.

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Date	Place	Discharge (sec.-ft.)
June 7		3.98
June 13		3.74
June 20		3.25
July 11		2.46
July 30		1.49
May 2, 1927		5.62
May 2		6.21
June 24		2.72
May 15, 1928		2.72
June 5		2.70
June 20		2.28
June 1932		6.58
July 11, 1932		3.06
June 2, 1933, White River above all diversions except that of A. Lee		8.01
June 8, White River above all diversions except that of A. Lee		9.35
June 14, White River above all diversions except that of A. Lee		6.82
June 23, White River above all diversions except that of A. Lee		5.28
July 12, White River above all diversions except that of A. Lee		3.35
July 17, White River above all diversions except that of A. Lee		3.23
May 5, 1935, White River above all diversions except that of A. Lee		[2]10.78
Apr. 29, 1936, White River at Berryman-Rosevear diversion		[2]13.31
May 2, White River above all diversions except that of A. Lee		20.91
May 5, White River above all diversions except that of A. Lee		17.40
May 7, White River above all diversions except that of A. Lee		14.80
May 12, White River above all diversions except that of A. Lee		10.50
May 16, White River above all diversions except that of A. Lee		9.25
May 19, White River above all diversions except that of A. Lee		5.20
May 23, White River above all diversions except that of A. Lee		4.65
May 26, White River above all diversions except that of A. Lee		5.30
May 30, White River above all diversions except that of A. Lee		6.11
June 2, White River above all diversions except that of A. Lee		7.56
June 5, White River above all diversions except that of A. Lee		6.10
June 9, White River above all diversions except that of A. Lee		5.01
June 16, White River above all diversions except that of A. Lee		4.08
June 19, White River above all diversions except that of A. Lee		3.80
June 23, White River above all diversions except that of A. Lee		3.60
June 27, White River above all diversions except that of A. Lee		3.35
July 2, 1937, Measurement made above McQuean Ranch diversion		6.15
July 7, Measurement made above McQuean Ranch diversion		5.30
July 12, Measurement made above McQuean Ranch diversion		4.61
July 15, Measurement made above McQuean Ranch diversion		4.22
July 19, Measurement made above McQuean Ranch diversion		4.28
July 23, Measurement made above McQuean Ranch diversion		4.00
July 29, Measurement made above McQuean Ranch diversion		4.00
June 24, 1943, White River above all diversions except that of A. Lee		[4]4.05

Water Creek, in Water Canyon, is the only other perennial stream in the valley. Throughout the year water flows in its channel from the springs at its head to a point a few miles southwest of the mouth of Water Canyon. The discharge of Water Creek is carried in an irrigation ditch to the Peacock Ranch about 5 miles north of Lund. The measured discharge of Water Creek at the mouth of Water Canyon was 0.89 second-foot on December 22, 1947. It is reported that the creek discharges about 3 second-feet at this point during the spring runoff period from April to June and that about 1 second-foot flows continuously during the low runoff period from September to April.

The intermittent streams in the smaller canyons of the mountains discharge water for only short periods during the spring runoff and when flash floods occur.

[2]Measurement by F. N. Dondero.
[3]Measurement by H. A. Shamburger, Assistant State Engineer of Nevada.
[4]Measurement by A. M. Smith, State Engineer of Nevada, and F. N. Dondero.

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CLIMATE

The climate of eastern Nevada is arid to semiarid owing to the low precipitation and high rate of evaporation. The areal distribution of precipitation is irregular, but the existing records and the vegetative cover indicate that the greatest precipitation occurs on the higher mountain slopes and that the driest areas are in the lower parts of the valleys. The temperature ranges considerably both diurnally and seasonally.

PRECIPITATION

The accompanying Figure 2 and Tables 2, 3, 4, and 5, based on records of the U. S. Weather Bureau and the Nevada Cooperative Snow Surveys, show the average monthly precipitation, the annual precipitation, and the cumulative departure from the average annual precipitation for 59 years (1888 to 1947) at McGill, for 34 years at Adaven (Sharp), and for 17 years at Kimberly. They also show the monthly and annual precipitation at Sunnyside and Currant. Sunnyside is in White River Valley and Kimberly, McGill, Adaven (Sharp), and Currant are in adjacent valleys. Kimberly, the highest U. S. Weather Bureau Station in Nevada in 1948, is near the drainage divide at the north end of White River Valley; McGill is in Steptoe Valley; Adaven is in Garden Valley, and Currant is in Railroad Valley. The last two stations are at altitudes respectively slightly higher and slightly lower than the average altitude of the floor of White River Valley. Probably the average precipitation at the two stations approximates closely that in White River Valley. The amount of precipitation to be expected at higher altitudes is indicated by the record of the Kimberly station. Snowfall at higher altitudes during the winter months is also indicated by one snow-survey course at Murry Summit, altitude 7,250 feet, established in 1936 by the Nevada Cooperative Snow Surveys. Comparison of the precipitation at Kimberly with that of the lower surrounding stations shows an increase with altitude.

Precipitation at each station varies greatly from year to year, as shown in Table 2. At McGill it has ranged between 5.58 inches and 18.01 inches, at Adaven (Sharp) between 5.19 and 23.55 inches, and at Kimberly between 6.86 inches and 19.95 inches. For the most part the seasonal variation is regional, but there are some local variations, as in 1931, when precipitation at McGill and Kimberly was respectively about 3 and 4 inches below normal and at Adaven (Sharp) 2 inches above normal.

The cumulative departure from average annual precipitation

at McGill, Kimberly, and Adaven (Sharp) is shown in Figure 2. Such graphs are of particular interest in studies of ground-water conditions because they portray long-term deficiencies and excesses of precipitation and because changes of storage in ground-water reservoirs usually reflect these deficiencies and excesses. The cumulative departure graphs show that at McGill the period 1890 to 1900 was one of above-normal precipitation and that the period 1900 to 1910 was about normal. The trend was then downward to 1915, generally upward until 1923, and then downward until 1935. Since 1935 it has averaged about normal. The graphs for Adaven (Sharp) and Kimberly cannot be compared directly with that for McGill because they do not cover the same period, but the trend was generally downward during the first part of the records, until 1935, and then upward.

Precipitation is distributed rather evenly through the year at McGill and Kimberly but not so evenly at Adaven (Sharp), Sunnyside, and Currant, although commonly the months of highest and lowest precipitation are the same. Generally less than 20 percent of the annual precipitation occurs during June, July, and August, the driest period of the year, in the form of afternoon showers and cloudbursts. About 60 percent occurs as snow between December and May.

TEMPERATURE

Long-period temperature records are available for two climatological stations, McGill and Adaven (Sharp). These records are summarized in Table 5, where the average, minimum, and average maximum temperatures for the period of record at each station are listed. The highest temperature of record at McGill was 104° F.; at Adaven (Sharp), it was 105° F. The lowest temperature of record at McGill was —27° F.; at Adaven (Sharp), it was —22° F.

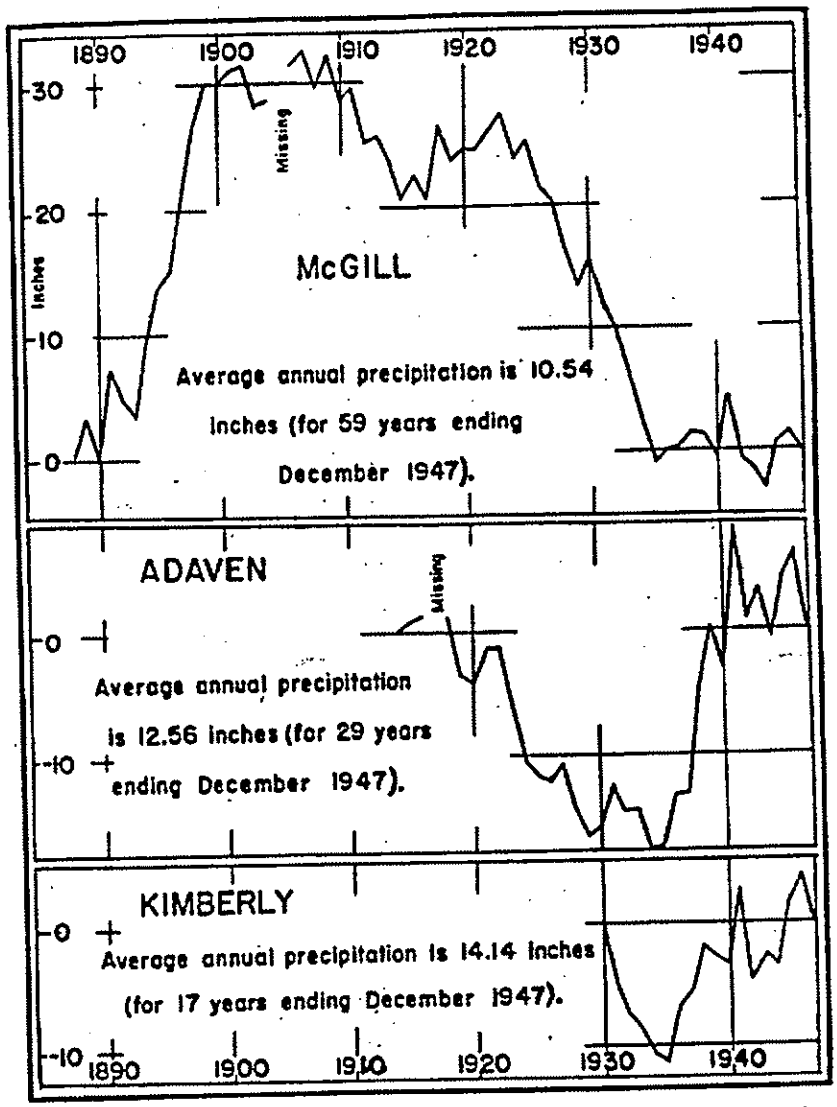

FIGURE 2—Graphs showing cumulative departure from average annual precipitation at three stations in eastern Nevada.

TABLE 2

Annual Precipitation, in inches, at McGill, Kimberly, and Adaven (Sharp), Nevada

(Records from U. S. Weather Bureau)

Year	McGill[1]	Adaven[2]	Year	McGill[1]	Kimberly[3]	Adaven[2]
1888	10.88	------	1920	11.39	------	12.10
1889	13.54	------	1921	10.52	------	15.42
1890	7.16	------	1922	11.37	------	12.66
1891	18.01	------	1923	11.92	------	8.34
1892	7.89	------	1924	7.04	------	7.47
1893	9.14	------	1925	11.82	------	11.36
1894	16.71	------	1926	7.11	------	12.22
1895	14.77	------	1927	9.30	------	13.75
1896	11.82	------	1928	6.56	------	9.15
1897	17.20	------	1929	7.56	------	10.41
1898	15.06	------	1930	12.72	------	13.16
1899	14.35	------	1931	6.81	9.52	15.92
1900	10.47	------	1932	8.44	11.26	10.44
1901	11.51	------	1933	6.29	12.01	12.66
1902	10.91	------	1934	7.01	12.15	9.29
1903	7.30	------	1935	7.00	13.45	12.73
1904	11.00	------	1936	11.48	18.70	16.82
1905	------	------	1937	10.90	15.45	13.74
1906	13.42	------	1938	11.52	17.53	21.32
1907	11.77	------	1939	10.39	13.33	16.94
1908	7.45	------	1940	8.58	13.63	9.65
1909	13.15	------	1941	15.26	19.95	23.55
1910	7.01	------	1942	5.58	6.36	5.19
1911	11.40	------	1943	9.95	16.46	14.93
1912	6.15	------	1944	8.59	13.12	8.71
1913	11.18	------	1945	14.35	19.45	17.42
1914	8.62	------	1946	11.15	16.14	14.28
1915	7.44	13.44	1947	9.12	10.25	6.51
1916	12.36	13.02	Ave.	10.54	14.14	12.56
1917	8.67	------				
1918	16.21	------	1931–1947			
1919	7.94	7.47	Ave.	9.60	14.14	13.48

[1]Altitude 6,240 feet; location, sec. 23, T. 18 N., R. 64 E.
[2]Altitude 7,250 feet; location, sec. 8, T. 16 N., R. 62 E.
[3]Altitude 6,250 feet; location, sec. 16, T. 3 N., R. 57 E.

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TABLE 3

Average monthly and annual precipitation, in inches, at five stations in eastern Nevada

(Records from U. S. Weather Bureau)

Name of Station	Length of record (years)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Adaven[1] (Sharp)	31	1.32	1.52	1.45	1.11	0.89	0.37	0.93	1.40	0.41	1.13	0.75	1.27	12.56
Currant[2]	5	.33	.39	1.40	.95	.38	.54	.13	.59	.36	.90	.73	.44	7.14
Kimberly[3]	17	1.60	1.85	1.56	1.49	.91	.67	.90	.94	.78	1.05	.88	1.51	14.14
McGill[4]	59	.94	.92	1.10	1.11	1.23	.63	.66	1.02	.63	.82	.66	.82	10.54
Sunnyside[5]	[6]6	.84	.86	2.28	.34	.93	.30	.77	.34	.46	.33	.32	1.39	9.17

[1]Altitude 6,250 feet; location, sec. 16, T. 3 N., R. 57 E.
[2]Altitude 5,183 feet; location, sec. 8, T. 10 N., R. 58 E.
[3]Altitude 7,250 feet; location, sec. 8, T. 15 N., R. 62 E.
[4]Altitude 6,340 feet; location, sec. 28, T. 15 N., R. 64 E.
[5]Altitude 5,334 feet; location, sec. 29, T. 7 N., R. 62 E.
[6]Incomplete record.

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TABLE 4

Depth and water content of snow, in inches, at Murry Summit, Nevada[1]

Year	Date	Snow	Water	Date	Snow	Water
1937	Mar. 1	25.0	6.4	Apr. 1	12.8	5.1
1938	Feb. 28	13.8	3.8	Apr. 1	6.4	2.2
1939	Mar. 3	15.1	3.3		No survey	
1940	Mar. 2	11.1	3.2	Apr. 1	6.1	.4
1941	Mar. 1	12.3	4.3	Apr. 1	6.8	4.8
1942	Mar. 2	15.0	3.3	Apr. 2	7.7	2.3
1943	Mar. 1	14.8	5.0	Apr. 1	.0	.0
1944	Mar. 1	22.0	5.3	Apr. 1	14.9	5.6
1945	Mar. 1	15.5	4.9	Apr. 4	16.9	5.8
1946	Mar. 4	11.7	3.4	Apr. 2	12.1	3.0
1947	Feb. 27	10.3	4.3	Apr. 2	.0	.0
1948	Feb. 27	5.3	1.6	Mar. 29	14.3	4.2
Average		14.3	3.9	Average	8.9	3.1

Miscellaneous measurements—

Jan. 2, 1937	22.2	2.9	Jan. 2, 1942	11.8	2.0
Feb. 1, 1937	25.1	4.8	Feb. 2, 1942	12.9	2.3
Jan. 3, 1938	5.1	.7	Feb. 1, 1943	16.5	3.7
Jan. 31, 1938	6.1	.9	Jan. 3, 1944	12.9	2.1
Feb. 2, 1939	14.7	2.4	Feb. 1, 1944	13.1	2.3
Jan. 1, 1940	.0	.0	Jan. 2, 1945	13.1	3.0
Feb. 2, 1940	9.7	2.4	Feb. 1, 1945	14.6	3.4
Jan. 3, 1941	8.2	.5	Jan. 2, 1946	9.8	1.6
Feb. 1, 1941	12.8	2.9	Feb. 1, 1946	13.9	2.6

[1]Established August 12, 1936 by E. Hill and C. Elges. Located on Nevada National Forest in sec. 25, T. 16 N., R. 62 E. Elevation 7,250 feet. Course revised in 1947 to 10 samples at 100 feet. Surveys by District Forest Ranger, Ely, Nevada. Data from reports of the Nevada Cooperative Snow Surveys.

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TABLE 5

Average, average maximum, and average minimum monthly and annual temperature, in degrees Farenheit, at McGill and Adaven (Sharp), Nevada

(Records from U. S. Weather Bureau)

McGill, Altitude 6,340 feet

(Location: sec. 28, T. 18 N., R. 64 E., in Steptoe Valley, about 40 miles air line northeast of Lund.)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Length of record (years)
Average	25.5	29.0	34.8	42.0	51.0	60.1	67.4	64.5	56.3	45.7	35.5	27.2	45.0	50
Average maximum	39.4	42.7	50.7	59.8	69.5	80.4	88.4	86.5	77.3	64.7	52.0	41.2	62.8	27
Average minimum	15.9	19.9	25.5	32.1	39.5	48.5	56.0	54.2	44.9	34.1	24.3	17.0	34.4	27

Adaven (Sharp), Altitude 6,250 feet

(Location: sec. 16, T. 2 N., R. 57 E., in White River drainage area, about 58 miles air line southwest of Lund.)

Average	29.1	31.8	37.9	45.1	55.3	63.2	70.3	68.2	60.1	49.0	39.0	31.1	48.3	26
Average maximum	42.0	44.3	52.3	61.0	70.5	80.5	87.5	85.6	77.1	64.4	54.0	44.2	63.6	26
Average minimum	15.7	18.5	23.4	29.2	36.9	44.6	52.9	51.1	43.6	33.6	24.0	18.0	32.6	26

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According to the records of the U. S. Weather Bureau, the frost-free growing period at McGill has ranged from 27 days in 1891 (July 12 to August 8) to 150 days in 1933 (May 13 to October 20) and has averaged 120 days (May 31 to September 20) during a 50-year period of record. The frost-free growing period at Adaven has ranged from 87 days in 1925 (June 22 to September 17) to 155 days in 1922 (May 29 to October 29) and has averaged 121 days (June 1 to September 29) during a 33-year period of record. Inasmuch as the altitudes of these stations are from 300 to 1,200 feet above the floor of White River Valley, the growing season there is probably a little longer. The growing period in White River Valley is usually satisfactory for the growth of hay and other frost-resistant or rapidly maturing crops.

VEGETATION

Between altitudes of 6,000 to 9,000 feet the highlands that border White River Valley commonly are covered by a vigorous growth of juniper (mostly *Juniperus utahensis*) and piñon pine (*Pinus monophylla* and *Pinus edulis*), associated with sagebrush (*Artemisia tridentata*), blackbrush (*Coleogyne ramosissima*), little rabbit brush (*Chrysothamnus stenophyllus*), and other typical members of the Northern Desert Shrub plant association. Small growths of white fir (*Abies concolor*) and other large evergreens are commonly found in well-shaded mountain canyons between altitudes of 7,500 and 11,000 feet, but slopes well timbered with trees of this type are not to be found.

The alluvial apron and the valley floor are commonly covered by sagebrush, little rabbit brush, and associated shrubs, except in places where the water table is near the land surface.

Growths of rabbit brush (*Chrysothamnus graveolens*), salt grass (*Distichlis spicata*), greasewood (*Sarcobatus vermiculatus*), and other phreatophytes—plants that habitually obtain their water supply from the zone of saturation either directly or through the capillary fringe—are commonly found where the water table is near the land surface. Phreatophytes transpire large quantities of ground water during their growing season. Determination of the use of water by phreatophytes is an important and necessary factor in estimating the discharge of ground water and the amount of ground water available in the desert valleys and basins of Nevada. Large areas in White River Valley are covered by phreatophytes. These are in the channel of White River south of Lund, including most of the Wilson Meadows, and

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in the eastern part of The Cove. An unusual phreatophyte, locally referred to as "swamp cedar," grows in small areas west of White River, especially in sec. 33, T. 11 N., R. 61 E. This tree has been tentatively identified as a variety of the Rocky Mountain juniper (*Juniperus scopulorum*) or possibly a hybrid between the Rocky Mountain juniper and the western or Utah juniper (*Juniperus utahensis*).[1] It also grows in Spring Valley, about 30 miles east of White River Valley, in marshlands and other places where the water table is near the land surface. These are the only two localities where the writers have observed this phreatophyte.

The mapped area of phreatophytes as shown on Plate 1 closely conforms to the area in which the water table is within 10 feet of the land surface in White River Valley.

GEOLOGY AND WATER-BEARING CHARACTERISTICS OF THE ROCKS

GENERAL RELATIONS

The rocks of White River Valley may be divided into two general groups on the basis of their age, origin, occurrence, and influence on the occurrence and movements of ground water. These groups are: (1) The older sedimentary and igneous rocks in the mountains and foothills; and (2) the lake beds and alluvial deposits of the valley.

OLDER SEDIMENTARY AND IGNEOUS ROCKS

The stratigraphy of the older sedimentary rocks in White River Valley has been studied in detail only in the Robinson mining district in the vicinity of Ely, Ruth, and Kimberly, adjacent to the northeast part of the valley. Reconnaisance studies have been made, also, in Cave Valley on the east side of the Egan Range. Only reconnaisance studies, mostly conducted during the present investigation, have been made in other parts of the valley. However, these reconnaisance studies indicate that the general stratigraphic sequence of the older rocks is similar to that in the Robinson district and in Cave Valley. The center stratigraphic column in Figure 3 shows the general relations in the Robinson district and in Cave Valley. Columns that diagramatically illustrate the Paleozoic stratigraphy in the Eureka and Pioche mining districts, the areas closest to the Robinson district and White River Valley in which detailed geologic studies have been made, are shown, also, in Figure 3.

[1]Personal correspondence with Robert L. Brown, Regional Nursery Division, Pacific Coast Region, Soil Cons. Service, Dec. 22, 1947.

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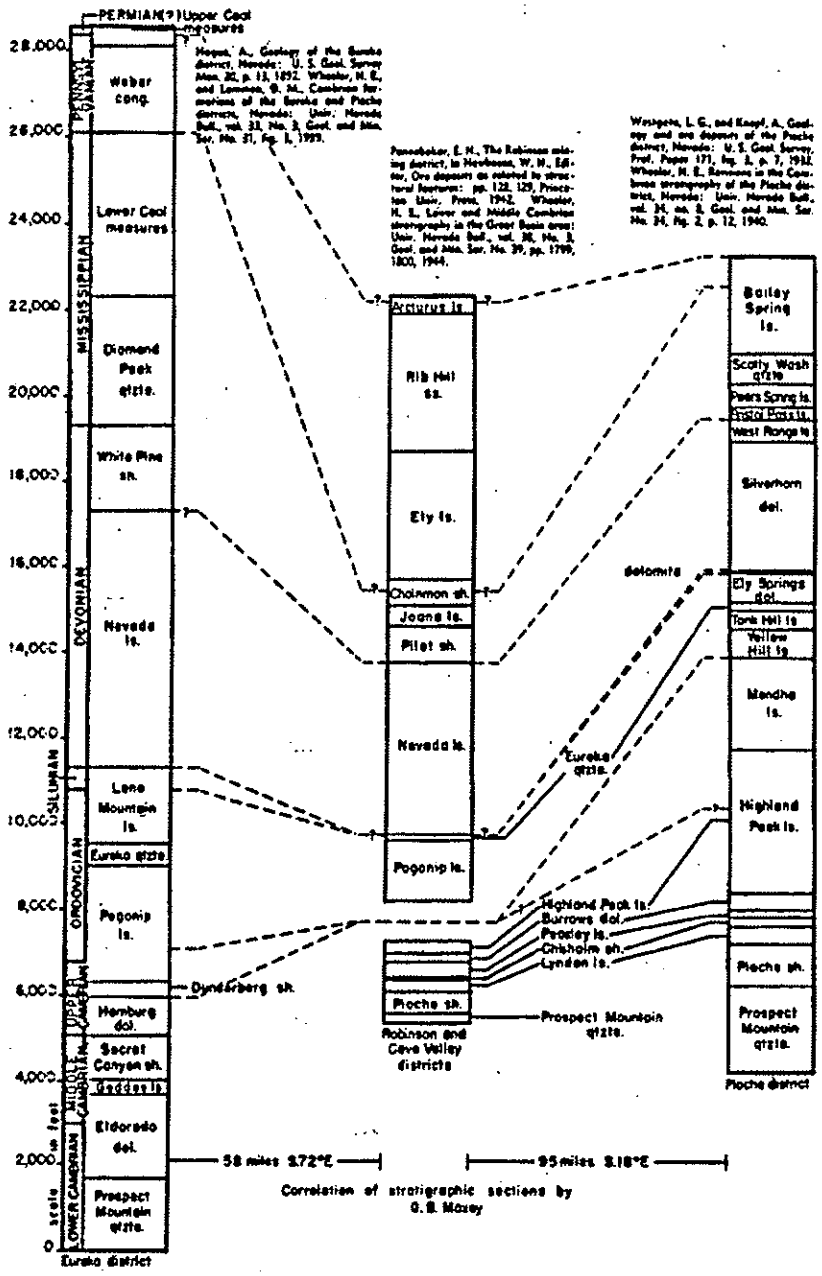

FIGURE 3—Diagrammatic correlation of Paleozoic stratigraphic columns in the Eureka, Pioche, and Robinson mining districts, and Cave Valley, Nevada.

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Rocks of Paleozoic age form the main bulk of the ranges adjacent to White River Valley. Rocks of Devonian to Pennsylvanian age crop out in the north part of the Egan Range, on the drainage divide and in the foothills at the north end of the valley, and in the foothills along the west side of the valley as far south as The Cove. Farther south, rocks in the mountains along both sides of the valley are commonly older and belong to formations of Cambrian to Devonian age. Rocks of Ordovician and Devonian age crop out along the crests of the White Pine and Grant Ranges and rocks of later Paleozoic age form the lower parts of the east sides of these ranges. Rocks of early Paleozoic age form a few small isolated hills or buttes north of Moon River Spring in the south end of the valley.

Detailed lithologic descriptions of the formations as they appear in the Robinson, Patterson, Pioche, and Eureka mining districts are available in papers by Westgate and Knopf,[1] Wheeler and Lemmon,[2] Wheeler,[3] Hague,[4] and Pennebaker,[5] and therefore are not given in this report.

In summary, most formations in the mountains adjacent to White River Valley consist of well-indurated shale, sandstone, quartzite, dolomite, and limestone. Limestone and dolomite are the predominant rock types. They are commonly noncavernous, even where jointed and faulted, but parts of two formations, the Pogonip and Nevada limestones, are moderately cavernous.

Extrusive rocks are exposed in a large area in the foothills in the northwest and west parts of the valley. These rocks also crop out over small areas in the northeast and southeast parts of the valley. They commonly consist of rhyolite, andesite, and minor flows of basalt. The extrusive rocks are associated with intrusive porphyries and quartz monzonite in the vicinity of Shingle Pass in the south part of the Egan Range, in the Robinson mining district, and on the west slopes of the White Pine and

[1]Westgate, L. G., and Knopf, A., Geology and ore deposits of the Pioche district, Nevada: U. S. Geol. Survey Prof. Paper 171, 1932.

[2]Wheeler, H. E., and Lemmon, D. M., Cambrian formations of the Eureka and Pioche districts, Nevada: Univ. Nevada Bull., vol. 33, no. 3, Geol. and Min. Ser. No. 31, 1939.

[3]Wheeler, H. E., Revisions in the Cambrian stratigraphy of the Pioche district, Nevada: Univ. Nevada Bull., vol. 34, no. 8, Geol. and Min. Ser. No. 34, 1940.

Lower and Middle Cambrian stratigraphy in the Great Basin area: Univ. Nevada Bull., vol. 38, no. 3, Geol. and Min. Ser. No. 39, pp. 1793–1800, May 1944.

[4]Hague, A., Geology of the Eureka district, Nevada: U. S. Geol. Survey Mon. 20, 1892.

[5]Pennebaker, E. N., The Robinson mining district, in Newhouse (Editor), Ore deposits as related to structural features: pp. 128–136, 1942.

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Grant Ranges. The porphyries and monzonites in the Robinson mining district intruded Pennsylvanian and possibly Permian rocks and were cut by the extrusive rocks. All the flow rocks adjacent to and in White River Valley are stratigraphically overlain by the Tertiary and Quaternary lacustrine and alluvial sediments. Similar flow rocks cut through limestones of Pennsylvanian age and are covered by the Panaca formation of Pliocene age[6] in the Pioche district. This stratigraphic relationship is common in other nearby areas. Therefore, the age of the flows is tentatively assigned to the Tertiary period because they occupy a position similar to that of the Tertiary(?) flows of the Pioche and other nearby districts where detailed studies have been made.

The Tertiary(?) flow rocks commonly are dense and therefore not highly permeable. They are considerably jointed, and in some areas individual flows are separated by thin sedimentary beds.

The physical characteristics of most of the older sedimentary rocks and of the igneous rocks indicate that they are not good water-bearing formations and that little water could be developed from wells penetrating them. Primarily they are barriers to movement of ground water on either side of the valley. They may partly impede ground-water movement at the north end of White River Valley. Thus, so far as ground-water movements are concerned, the valley is isolated from adjoining valleys on the east and west but probably receives some ground water from Jakes Valley to the north. The moderately cavernous parts of the Pogonip and Nevada limestones are probably good aquifers that store and transmit large quantities of water where they are beneath the regional water table. Small quantities of water probably percolate into joints and along faults in the other formations and in the igneous rocks and eventually seep into the alluvial deposits or come to the surface as small springs.

TERTIARY AND QUATERNARY ALLUVIAL AND LACUSTRINE DEPOSITS

The alluvial deposits of gravel, sand, silt, and clay that make up the valley fill contain the most productive aquifers and yield all the water discharged from wells and by soil evaporation and transpiration from plants in White River Valley. These deposits occur over most of the valley lowland. The contact between the alluvial and lacustrine deposits and the older rocks (see pl. 1) is

[6]Phoenix, D. A., Geology and ground water in the Meadow Valley Wash drainage area, Nevada, above the vicinity of Caliente: State of Nevada, Office of the State Engineer, Water Resources Bull., No. 7, pp. 32–38, 1948.

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higher in the north part of the valley than in the south part. The maximum altitude of the contact is about 7,000 feet and the average altitude is about 6,000 feet. The alluvial and lacustrine deposits range in thickness from a featheredge to a maximum of at least 1,300 feet. According to the log of the White Pine County test well (12/62-5D1) drilled to a depth of 1,300 feet, the well ended in alluvial or lacustrine materials. This well has been destroyed and it is now impossible to check the depth. Another county test well (12/61-13D1) was drilled to a depth of 560 feet and ended in lacustrine deposits. All other known wells in the valley are reported or known to be shallower than these test wells. Thus the maximum thickness of the alluvial and lacustrine deposits in White River Valley is apparently more than 1,300 feet. These sediments in White River Valley may be grouped into the following four units on the basis of their age, origin, and distribution: (1) The older lacustrine deposits of possible middle to late Tertiary age; (2) the alluvial-fan deposits, formed probably during the late Tertiary and in the Quaternary period; (3) the Pleistocene river deposits; (4) deposits of Recent age which occur commonly in the bottoms of the washes and on the valley floor. These units are not differentiated on Plate 1 because detailed geologic mapping was not within the scope of this investigation.

The older lacustrine deposits crop out near the Adams-McGill reservoir in the south part of White River Valley. They consist of fine sand, silt, clay, containing considerable limey materials, most of which is probably caliche. The beds are horizontal and apparently have not been disturbed by faulting or folding. The altitude of the top of the beds near the reservoir is about 5,350 feet. Outcrops of these deposits have not been identified in the north part of the valley as they have been covered by sediments deposited during later geologic time. In the vicinity of Preston and Lund, it appears that the fine-grained materials penetrated by wells below a depth of about 150 feet, and an altitude of about 5,450 feet, are part of these lacustrine sediments. The lithology and stratigraphic position of these sediments closely resemble other lacustrine sediments studied in nearby areas, such as the Panaca formation[7] in the Pioche district and parts of the Humboldt formation along the Humboldt River. Therefore, it is believed likely that they were deposited since middle Tertiary time and before the close of the Pliocene epoch.

[7]Phoenix, D. A., op. cit. p. 84.

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The lithology of the alluvial-fan deposits is well known from numerous exposures along the higher parts of the alluvial apron and from several logs of wells drilled in the central part of the valley. Near the mountains, in the upper part of the alluvial apron, they commonly consist of massive to thin beds of coarse, angular, poorly assorted gravel and sand. These beds are of local derivation and of relatively high permeability. They dip away from the mountains at angles of 8° to 15°. Lower down on the alluvial apron the beds become more sandy and silty and dip at lower angles. The beds of coarser materials become thinner and interfinger with thick lenses of silt and clay along the toe of the apron in the central part of the valley. Deposition of the materials in the alluvial apron may have been contemporaneous with that of the lacustrine deposits and probably continued through early Pleistocene time. The apron was dissected during late Pleistocene(?) time but later it became a depositional area and deposition is continuing along channels incised in it.

The character and position of these sediments is of much significance in the occurrence of ground water in the valley. Nearly all the relatively heavy precipitation in the mountains is on areas tributary to the outcrops of the gravels. That fraction of the precipitation not lost by evaporation or transpiration recharges the ground-water reservoir either by percolation in the soil mantle and the underlying rocks thence into the valley fill; or by runoff on the surface of the alluvial fans and thence into the valley fill.

The toes of the alluvial fans are truncated by the old channel of White River. The old river bed and its tributaries are well defined by escarpments throughout the length of White River Valley. The confluence of the old White River channel and the large tributary, Jakes Wash, is just south of Preston. The main river channel extended northwesterly into the White Pine Mountains, whereas Jakes Wash drained the north and northwestern parts of the Egan Range. Thus the present drainage pattern was established at least in late Pleistocene time. These old channels range from a quarter to half a mile in width. The old channel is about 1½ miles wide south from its confluence with Jakes Wash to Lund. South of Lund to the south end of White River Valley it averages about three-quarters of a mile wide.

The base of the escarpments marginal to the old river channel marks the contact of the river deposits with the alluvial-fan materials. The river deposits consist of beds and lenses of well-sorted to poorly sorted, well-rounded gravel with some sand and

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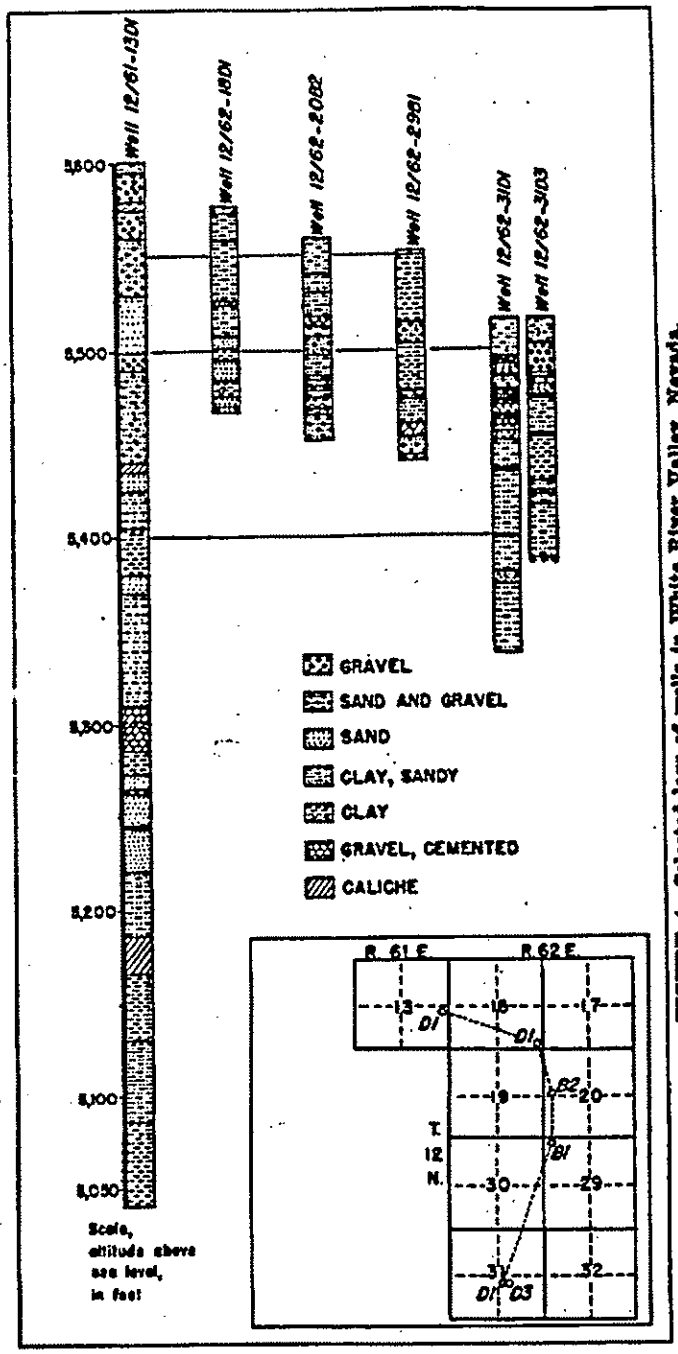

FIGURE 4.—Selected logs of wells in White River Valley, Nevada.

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silt. The thickness of these deposits may be as much as 150 feet in some places and probably averages about 50 feet. The river gravels were deposited by White River principally during late Pleistocene time. The well-sorted sands and gravels form highly permeable aquifers that are among the most productive in White River Valley.

Alluvial deposits of Recent age, consisting of silt and clay with some sand and gravel, occur locally in most of the large washes in White River Valley. These deposits commonly are thin and lie above the regional water table, but in a few places they may extend below the water table and may prove to be important water-bearing beds. Figure 4 shows, graphically, the logs of several wells in the valley.

GROUND WATER

OCCURRENCE

All the ground water obtained from wells in White River Valley is drawn from the sand and gravel deposits of the valley fill. Most of it is taken from the highly permeable gravels and sands deposited in the old channels of White River along the axis of the valley. The river gravels of the old channels are in contact with the truncated lower ends of the alluvial apron and are more or less interconnected with the sand and gravel deposits of the alluvial apron. The river deposits probably average 50 feet in thickness. They are underlain, in part, by alluvial-apron sediments that also contain water-bearing sand and gravel lenses. Logs of wells drilled in the vicinity of Preston and Lund show that the alluvial-apron sediments may be about 120 feet thick and are underlain by less permeable lacustrine sediments of Tertiary age (see fig. 4). Thus the known productive water-bearing beds in White River Valley occur in the alluvial apron and the river-channel deposits ranging in depth from about 15 to 150 feet, depending upon the topographic location. The river gravels are commonly thinner and underlie smaller areas in the south part of the valley from Emigrant Springs to Hot Creek Ranch. Important water-bearing beds may occur only in the alluvial fans in the south part of the valley because there the relatively impermeable lacustrine sediments are near the surface or crop out nearly everywhere along the axis of the valley.

Springs in the valley fill yield large quantities of water. Most of them, such as Emigrant, Butterfield, and Flag Springs (see pl. 1) occur on the lower part of the alluvial apron. They are probably gravity springs, and most of the water that issues from

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them comes to the surface along the outcrop area of the relatively permeable water-bearing beds which overlie impermeable beds in the alluvial-fan deposits. Commonly the water table is near the surface in the vicinity of and downstream from the spring sites.

Arnoldson, Nicholas, Cold, and Preston Big Springs issue from the valley fill in the vicinity of Preston. The water table in the immediate vicinity of the springs, as shown by measurements of the water level in several nearby wells, is at least 60 feet beneath the land surface. Thus the water issuing from the springs is under artesian head. The following discussion is offered as a tentative explanation of the possible origin of these springs: Prior to the deposition of the valley fill, large springs issued from bedrock aquifers in the vicinity of the present site of Preston. During the deposition of the Tertiary lacustrine sediments the water issuing from the springs was under sufficient head to continue rising through the lake deposits. The large springs flowed with sufficient velocity to allow selective deposition of only the sandy or coarser particles at the spring sites. Thus relatively permeable channels were maintained through the lacustrine sediments, as they were deposited, the head at all times being sufficient to cause discharge at the spring orifices. Deposition of lacustrine sediments gradually gave way to deposition of fan sediments. Channels through these fan sediments probably were maintained by a process similar to that described above, and were isolated from the surrounding alluvial-fan sediments by deposition of wind-blown silt and clay which became fixed in the moist vegetated areas around the spring orifices. These inferences may be substantiated in part by the reported presence of thick zones of clay and silt around Preston Big Spring.[1]

Caliche does not crop out in the vicinity of the springs. There is no surficial evidence that the springs ever deposited sufficient quantities of calcareous material to form "pipes" or channels. Partial analyses by D. E. White,[2] Geologist, U. S. Geological Survey, show that the water from the springs does not deposit calcareous material at present. Leakage to the valley fill from the spring conduits is possible. However, on the basis of the assumptions made in the foregoing paragraphs, the spring conduits are enclosed by relatively impermeable sediments. These sediments would prevent lateral percolation of appreciable quantities of water. Further, the water table is deep in the immediate

[1]Oral communication from Soil Conservation Service, Ely, Nevada.
[2]Oral communication.

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vicinity of the springs. Substantial losses through the conduit walls would be expected to result in a ground-water level at or near the level of the spring orifices.

Ground water also occurs in the bedrock in and adjacent to White River Valley. Large quantities of water are discharged from Lund Spring, which issues from limestone near the southeast corner of Lund, and at Hot Creek Spring near Hot Creek Ranch in the south part of the valley. Lund Spring apparently flows out of crevices in cavernous limestone (Nevada(?) limestone), and Hot Creek Spring flows out of a highly faulted, cavernous part of the Pogonip(?) limestone. Several other smaller springs issue from bedrock, the most important being Moon River Spring about 3 miles southwest of Hot Creek Spring. In the mountainous areas numerous small springs issue from bedrock or from alluvium near bedrock. Many of them are intermittent and cease flowing during the dry part of the year and in periods of drought. Only small quantities of water occur in bedrock formations other than the Nevada and Pogonip limestones because the other rocks are relatively impermeable.

SPRINGS

The location and physical characteristics of the largest and most important springs in White River Valley are shown on Plate 1 and in Tables 6, 7, and 8. Most of the larger springs are thermal,[3] that is, the temperature of the water that issues from them is more than 10° F. higher than the average annual air temperatures in the valley. This higher temperature is inferred to indicate that some or all of the water that issues from the springs circulates to considerable depth following infiltration in the recharge area. The temperature of the water does not necessarily indicate the depth to which it circulates, because in the Great Basin the temperature gradient of the earth ranges considerably from place to place. The depth to which water circulates probably varies in the different spring systems. The time required for the water to circulate probably varies also in the different spring systems. The temperature of water issuing from spring systems is controlled by: (1) Rock temperature, (2) depth of circulation, (3) length of the system, and (4) time required for circulation. Thus the temperature of water issuing from a spring system is the resultant effect of the several factors. For example, the higher temperature of the water from Mormon

[3]Stearns, N. D., Stearns, H. T., and Waring, G. A., Thermal springs in the United States: U. S. Geol. Survey Water-Supply Paper 679-B, p. 61, 1937.

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Spring does not necessarily show that it circulates more deeply than the waters of lower temperature from Preston Big or Cold Springs. Reconnaissance study of the geology of the recharge areas and the boundaries of the drainage area of the valley indicates that the water discharged from springs originates as precipitation within the drainage boundaries of White River and Jakes Valleys.

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TABLE 6

Principal springs in White River Valley, Nevada

Number and location	Name and owner[1]	Geology	Temperature (°F.)	Discharge: Date of measurement	Discharge: Second-feet	Remarks
		NYE COUNTY				
6/60-25B1	Moon River Spring—Don Hutchings	Issues from valley alluvium adjacent to hill of Paleozoic limestone	92		[2]2	
6/61-18A1	Hot Creek Spring—Whipple Bros.	Issues from valley alluvium adjacent to hill of Paleozoic limestone	93	4- 6-35	15.34	Measured by F. W. Millard and Son. Analysis.
7/62-28B1	Butterfield Springs—Whipple Bros.	Issues from two orifices along lower slopes of alluvial fan			[2]2.5	
7/62-32D1	Flag Springs—Hendrix Bros.	Issues from several orifices along lower slopes of alluvial fan			[2]2.5	
9/61-32D1	Mormon Spring—Don Eldridge	Issues from valley alluvium about 1 mile east of bedrock hills	100		4.22	Recorded from Water-Supply Paper 679-B, p. 165.
9/62-19D1	Emigrant Springs—Don Eldridge	Issues from several orifices along lower slopes of alluvial fan	67		[2]3	
		WHITE PINE COUNTY				
11/62-4A1	Lund Spring—Lund Irrigation Company and others	Issues from alluvium about 25 feet from surface contact with bedrock (limestone)	66	10-27-10	5.36	Measurement by Office of Nevada State Engineer.
				3-16-35	9.34	Measurement by Scott and Titus for Lund Irrigation Co. Spring orifice lowered.
				3-16-35	10.19	Measurement by Scott and Titus for Lund Irrigation Co. Spring orifice lowered.
				3- 6-36	6.39	Measurement by Office of Nevada State Engineer.

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TABLE 6, WHITE PINE COUNTY—*Continued*

Number and location	Name and owner[1]	Geology	Temperature (°F.)	Discharge: Date of measurement	Discharge: Second-feet	Remarks
				1-23-37	7.22	Measurement by C. H. Wainwright for Lund Irrigation Co.
				5-17-44	8.14	Measurement by Office of Nevada State Engineer.
				5- 9-47	9.49	Measurement by Office of Nevada State Engineer.
12/61-2A1	Preston Big Spring—Preston and Lund Irrigation Companies	Issues from valley alluvium, probably through a conduit, and is under artesian pressure		5- 8-47	8.64	Measurement by Office of Nevada State Engineer.
				For other measurements see Table 7		
12/61-12B1	Cold Spring—Lund Irrigation Co.	Issues from valley alluvium, probably through a conduit, and is under artesian pressure	79	5- 9-47	1.74	Measurement by Office of Nevada State Engineer.
				For other measurements see Table 7		
12/61-12D1	Nicholas Spring—Lund Irrigation Co.	Issues from valley alluvium, probably through a conduit, and is under artesian pressure	71	5- 9-47	2.50	Measurement by Office of Nevada State Engineer.
				For other measurements see Table 7		
12/61-12D2	Arnoldson Spring—Preston Irrigation Co.	Issues from valley alluvium, probably through a conduit, and is under artesian pressure	72	5- 9-47	3.08	Measurement by Office of Nevada State Engineer.
				For other measurements see Table 7		
13/60-33A1	Williams Hot Spring—Jesse Gardner	Issues from fracture in interbedded sandstone, gravel, and limestone near exposures of Tertiary(?) flow rocks	124	.....	.11±	Record in Water-Supply Paper 679, p. 163.
			128	12-16-47	[2].3±	

[1]Springs are numbered by the same system as that described on page 54 for numbering wells. [2]Estimated.

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TABLE 7

Discharge, in second-feet, of Preston Big, Arnoldson, Cold, and Nicholas Springs, White River Valley, Nevada[1]

(Measurements by the Office of the State Engineer of Nevada except as noted)

Date	Preston Big Spring	Arnoldson Spring	Cold Spring	Nicholas Spring
Oct. 27, 1910	6.21	3.14	1.03	2.28
1913	7.96	3.66		
Aug. 14, 1913	[2]7.60			
Oct. 16, 1914	[2]7.00			
June 24, 1916	[2]8.00			
1922	----	3.52		
May 7, 1935	7.10	3.25	1.31	2.63
Aug. 13	7.21			
Mar. 6, 1936	8.48	3.86	1.34	2.68
Mar. 29	----	3.85	1.40	2.65
Mar. 30	8.10	3.85	1.40	2.65
Apr. 7	8.31	3.83	1.41	2.75
Apr. 29	8.39	3.80	1.44	2.74
May 2	8.29			
May 5	8.18	3.80	1.38	2.70
May 7	8.20	3.82	1.38	2.70
May 12	8.03	3.82	1.39	2.70
May 16	8.28	3.82	1.44	2.70
May 19	8.34	3.82	1.39	2.70
May 23	8.25	3.82	1.38	2.70
May 26	8.57	3.82	1.30	2.70
May 30	8.50	3.82	1.34	2.70
June 2	8.52	3.82	1.49	2.70
June 5	8.42	3.82	1.40	2.70
June 9	8.31	3.82	1.40	2.70
June 16	8.54	3.82	1.40	2.70
June 19	8.40	3.82	1.38	2.70
June 23	8.50	3.82	1.41	2.70
June 27	8.43	3.82	1.37	2.70
July 7	8.73	3.82	1.38	2.70
July 12	8.40	3.82	1.38	2.70
July 18	8.67	----	1.38	
July 19	8.52	3.82	1.40	2.70
July 26	8.50	3.82	1.38	2.70
Aug. 4	8.53	3.82	1.39	2.70
Aug. 15	8.50	3.82	1.39	2.70
Aug. 25	8.43	3.82	1.40	2.70
May 14, 1937	8.50			
Apr. 16, 1939	8.34			
Sept. 6	8.71			
Dec. 1	8.23			
Mar. 24, 1941	8.34			
June 13	8.39	3.73		
Apr. 16, 1943	9.04			
May 17, 1944	8.97	3.73		
July 27, 1945	8.58			
May 9, 1947	8.64	3.07	1.74	2.51

[1]Compiled by F. N. Dondero, Office Engineer, Office of the State Engineer of Nevada, from records of the Office of the State Engineer of Nevada.

[2]Measurement by the U. S. Geological Survey, Water Resources Division.

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SOURCE AND AMOUNT OF RECHARGE

As has been mentioned previously, the area enclosed by the drainage boundary of White River Valley can be considered an enclosed ground-water basin, except that it probably receives some underflow from Jakes Valley to the north and loses water by surface flow and underflow at the south end. There are no large areas of natural discharge in Jakes Valley. The valley is topographically separated from White River Valley by an alluvial divide at the head of Jakes Wash. It is believed that ground water moves south from Jakes Valley into White River Valley in the vicinity of Jakes Wash. Thus the ultimate source of the ground water is believed to be the precipitation within the White River Valley drainage boundary and the drainage boundary of Jakes Valley. However, only a small part of the water that falls as rain and snow on the drainage area reaches the ground-water reservoir. Large quantities are lost by transpiration and evaporation before the water has deeply penetrated the soil and rocks. An appreciable fraction of the precipitation probably never reaches the soil but falls on trees and other vegetation and evaporates following storms.

The average annual amount of recharge to ground water in White River Valley can be estimated from the precipitation and from the results of recharge studies in comparable areas. This requires a determination or estimate of average annual precipitation for the drainage area, from which the recharge is calculated as a percentage. An estimate for the precipitation in the White River Valley was made from a precipitation map[4] for the State of Nevada in which zones of average range of precipitation are designated. The zones are divided into the following ranges: less than 8 inches; 8 to 12 inches; 12 to 15 inches; 15 to 20 inches; and over 20 inches. The amount of water from the successive zones that reaches the ground-water reservoir is estimated as, 0, 3, 7, 15, and 25 percent of the precipitation in the respective zones. The percentages are adapted for this area from preliminary recharge studies in east-central Nevada. These studies consisted of estimating the ground-water discharge by natural losses from 13 valleys in east-central Nevada. The recharge for each valley was also estimated, using the rainfall-zone map as a basis. The recharge estimates were then balanced

[4]Hardman, George, Nevada precipitation and acreages of land by rainfall zones, Univ. Nevada Agr. Exper. Sta., mimeographed report and map, 10 pp., June 1936.

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by trial-and-error with the discharge estimates. They also compare favorably with percentages determined in Las Vegas Valley[5] by means of precipitation gages maintained at different altitudes in the Spring Mountains. The average annual ground-water recharge estimated on this basis is about 40,000 acre-feet for White River Valley, and about 13,000 acre-feet for Jakes Valley. This represents an approximation of the total recharge to ground water. The amount of ground water available to wells is estimated to be about 55 percent of the total recharge. (See page 46.)

MOVEMENT

Water from precipitation that enters the ground-water reservoir moves toward the axis of the valley. This is shown by the difference in altitude of the water levels in wells and mines high in the recharge areas and in wells in the lower part of the valley. For example, the altitude of the water level in the Alpha Mine near Kimberly is approximately 6,100 feet, the altitude of the water level in the Jakes Wash well (14/61–9C1, unsurveyed) is about 5,800 feet, and the altitude of the water table in the vicinity of Preston and Lund, as determined from measurements in many wells, ranges from 5,550 to 5,500 feet. Thus the slope of the water table and movement of the ground water are toward the valley axis.

The slope, and hence the movement of the ground water, and the shape of the water table in the vicinity of Lund and Preston are shown by water-level contours on Plate 2. The main ditch from Lund Spring extends north for about 1 mile to the north part of Lund. Most of the spring water is carried through this ditch for about 9 months of the year. During the remaining 3 months most of the spring discharge is diverted to the natural channel, which extends west from the spring. A ground-water ridge extends west from the north part of Lund, indicating that water in the main ditch recharges the ground-water reservoir in that vicinity. A smaller inflection of the water-level contours suggest ground-water recharge from the natural channel of Lund Spring, and from the tributary irrigation ditches in the area. White River and the main ditches from the springs near Preston also apparently contribute water to the ground-water reservoir. However, the water-level contours outside the immediate vicinity

[5] Maxey, G. B., and Robinson, T. W., Ground water in Las Vegas, Pahrump, and Indian Spring Valleys, Nevada (A summary): State of Nevada, Office of the State Engineer Water Resources Bull. No. 6, p. 16, 1947.

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of Lund are not controlled closely enough by wells to show definitely that contributions from the river and springs occur. The inference is supported, however, by measurements of losses between given points along the ditch from Nicholas, Cold, and Preston Big Springs. The discharge above and below a half-mile reach of the ditch immediately south of Preston was measured in April 1948 and found to be about 6.7 second-feet at the upper end of the reach and 6.0 second-feet at the lower end. Evaporation and transpiration were negligible and there were no diversions in this reach of the ditch. Thus these measurements indicate that about 0.7 second-foot percolated into the ground in that distance.

The southerly slope of the water table, and the resulting southerly movement of ground water throughout the length of the valley, is shown by measurements of the altitude of the water table. The southerly slope of the water table west of Lund is about 15 feet to the mile (see pl. 2). Measurements in the stretch along the river, south of latitude 38°15′ N., show that the slope of the water table steepens sharply. In February 1948 the water table was at the land surface at the south end of the area of transpiration in the southeast part of sec. 25, T. 5 N., R. 60 E. Five miles southeast of this point, the water level in the White River well (SW¼ sec. 36, T. 4 N., R. 61 E.), not shown on Plate 1, was 90 feet below land surface. Two miles farther southeast, in the Esplin well (SW¼ sec. 8, T. 3 N., R. 62 E.), not shown on Plate 1, the water level was about 220 below land surface. The land surface in this area has a gradient of about 30 feet a mile. The slope of the water table, then, is about 48 feet a mile for the 5-mile segment between sec. 25, T. 5 N., R. 60 E., and the White River well; between the White River well and the Esplin well the slope of the water table is on the order of magnitude of 95 feet a mile. Thus the data indicate that there is underflow to the south, out of the area, beneath White River channel.

DISCHARGE

Ground water is discharged within White River Valley by several large springs and by wells. All available records of the discharge of springs and wells were compiled as a part of the ground-water inventory. Most of these records are shown in Tables 6, 7, and 9. The estimated discharge of ground water from springs and wells, based on these records and on measurements made during the current investigation, was 40,000 and

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400 acre-feet of water, respectively, for 1947. The annual discharge from springs in previous years of record was about the same, but only about 180 acre-feet of water was discharged annually from wells between 1930 and 1940, and before 1930 the amount was probably less than 100 acre-feet.

All the water discharged within the valley by springs and wells is accounted for in the discharge inventory discussed in the following paragraphs, because this water is ultimately discharged from the valley by evapo-transpiration of areas of irrigated plants and native phreatophytes, by underflow, and by stream flow.

Ground water is discharged from White River Valley by two processes: (1) Evapo-transpiration, which includes evaporation from the soil and from free-water surfaces and transpiration by both native phreatophytes and cultivated plants, and (2) underground and surface outflow at the south end of the valley.

The scope of this investigation did not include detailed studies of evapo-transpiration rates in White River Valley. Therefore, estimates of the rates of evapo-transpiration[6] are based on data obtained from studies made in other parts of the West, especially those made by Lee[7] and White[8] in the Great Basin. These estimates were adapted to the climatic and hydrologic conditions of White River Valley and compare favorably with the values of consumptive use estimated by Piper, Robinson, and Park[9] in the Harney Basin, Oregon.

On this basis the annual consumptive use of alfalfa, cereals, and meadow hay, the chief cultivated crops in the valley, is estimated to be 1.25 feet. This estimate is substantiated in part by

[6]Evapo-transpiration here includes evaporation from free-water surfaces and "consumptive use," which is considered as the sum of the amount of water used by vegetative growth of a given area in transpiration or building of plant tissue and that evaporated from adjacent soil, in any specified time. The quantity is expressed as acre-feet per acre per year. Consumptive use is not equivalent to duty of water. Duty of water is the amount of water applied to crops and includes consumptive use, unavoidable losses such as percolation beyond the reach of plant roots, and some waste necessary to irrigate a given tract properly.

[7]Lee, C. H., An intensive study of the water resources of a part of Owens Valley, California: U. S. Geol. Survey Water-Supply Paper 294, 135 pp., 1912.

[8]White, W. N., A method of estimating ground-water supplies based on discharge of plants and evaporation from soil: U. S. Geol. Survey Water-Supply Paper 659-A, 105 pp., 1932.

[9]Piper, A. M., Robinson, T. W., and Park, C. F., Jr., Geology and ground-water resources of the Harney Basin, Oregon: U. S. Geol. Survey Water-Supply Paper 841, 189 pp., 1939.

data from studies made near Chino, California, by Blaney, Taylor, and Young.[10]

It is believed that most phreatophytes discharge only small, probably negligible amounts of water from the ground-water reservoir where the water table is more than 15 feet below the land surface. Salt grass, the most common phreatophyte in the area of transpiration apparently does not grow where the water table is more than 10 feet below the land surface and grows densely only where the water table is within 6 feet of the surface. In White River Valley few other phreatophytes grow even where the water table is within 15 feet of the land surface, and it is believed that they discharge very little water. Therefore, allowing for the distribution of phreatophytes and on the basis described in the preceding paragraph, it is estimated that the annual rate of evapo-transpiration is 0.8 foot in the area of transpiration in White River Valley. This estimate includes allowances for plant density, depth to the water table, and evaporation from small tracts of free-water surfaces.

The transpiration area (see pl. 1) comprises about 36,000 acres lying between the banks of White River channel and extending south from Lund to the south end of the valley. The area of irrigated land on which alfalfa, cereals, and meadow hay are grown is about 4,000 acres. Most of this land is in the vicinity of Preston and Lund and only small tracts lie in other parts of the valley (see pl. 1).

The estimated total annual discharge by evapo-transpiration is given below:

	Annual rate of discharge (feet)	Area (acres)	Annual discharge (acre-feet)
Native phreatophytes	0.8	36,000	28,800
Cultivated plants	1.25	4,000	5,000
Total discharge (approximate)			34,000

The quantity of water discharged by stream flow from the south end of White River Valley was estimated in February 1948 to be about 3 second-feet. Observations made during 1947 and 1948 indicate that the discharge might average 3 second-feet during the 6 months of the year when there is little irrigation in the valley. Possibly 1.5 second-feet flows during the early

[10] Blaney, H. F., Taylor, C. A., and Young, A. A., Rainfall penetration and consumptive use of water in Santa Ana River Valley and coastal plains: California Dept. Public Works, Water Resources Div. Bull. 33, pp. 85, 86, 1930.

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spring and fall, and no water is discharged by the stream during the 3 summer months. From these data it is estimated that the average annual discharge by streams from White River Valley into White River Wash is about 1,500 acre-feet.

Ground water is also discharged from the south end of the valley as underflow in White River Wash. It is possible to estimate this discharge by subtracting from the total recharge to White River Valley the combined discharge by evaporation and stream flow. The total recharge, assuming that the Jakes Valley drainage basin is tributary to White River Valley, is estimated to be 53,000 acre-feet, and discharge by evapo-transpiration and streams totals about 35,500 acre-feet. On this basis it is estimated that as much as 17,500 acre-feet of water leaves the valley as underflow. Of course, all errors in other factors are thrown into this figure.

Evaluation of ground-water discharge by underflow at the south end of White River Valley cannot be made by other methods because the thickness and permeability of the water-bearing materials in that area are unknown.

Hot Creek Spring annually discharges 11,000 acre-feet of water. Of this amount about 4,000 acre-feet may be accounted for by evapo-transpiration losses between the spring orifice and the south end of the valley. It is recognized that not all of this 4,000 acre-feet loss is supplied by Hot Creek Spring, as there is substantial underflow from White River and the springs to the north. Also, about 700 acre-feet of water from Hot Creek Spring probably is discharged from the valley as stream flow. According to these figures not less than 6,300 acre-feet of water from Hot Creek Spring alone must leave the valley as underflow. Consequently, the estimate of 17,500 acre-feet for the entire underflow out of the valley is believed not to be unreasonable.

The estimated total annual discharge of ground water from White River Valley is summarized below:

Process	Acre-feet
Evapo-transpiration	34,000
Underflow from south end of valley	17,500
Stream flow from south end of valley	1,500
Total discharge	53,000

UTILIZATION

Present — The principal use of the ground-water discharge from wells and springs is for irrigation in the vicinity of Lund

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and Preston and, to a lesser extent, near Emigrant Springs, Sunnyside, and Hot Creek Ranch. Wells and springs are also the principal source of water for domestic use and stockwatering throughout the valley.

The consumptive use of water in the irrigated areas is estimated to be about 5,000 acre-feet. The remaining 35,400 acre-feet of the 40,400 acre-feet of water discharged by wells and springs flows into the area of transpiration or returns by downward percolation to the ground-water reservoir in the valley lowland, from which it is later discharged by evapo-transpiration or by underflow out of the area. An indeterminate part of this 35,400 acre-feet of water is put to some beneficial use[11] to irrigate meadow pasture and to water stock.

Potential—Much of the water that is now discharged from the valley by evapo-transpiration, underflow, and stream flow can be utilized for irrigation by improving present methods of irrigation and by pumping water from the ground-water reservoir.

Hot Creek Spring annually discharges about 11,000 acre-feet of water, only a small part of which is used beneficially. The remainder flows into the Adams-McGill reservoir, thence south into White River Wash. Most of this water is lost by evaporation, transpiration, and percolation in the gravels of the wash. The discharge of this spring probably could be put to greater beneficial use on land of fair quality northwest of the spring. This can be accomplished either by construction of a new ditch or by low-lift pumping.

It is possible that as much as 12,000 acre-feet of ground water can be recovered annually by pumping from wells along the lower part of the alluvial fans and in the river channel in White Pine County. Probably 7,000 acre-feet can be recovered annually by wells in the part of the valley in Nye County. It is believed that such a withdrawal would not exceed the safe yield of the ground-water reservoir in the valley. Thus, about 30,000 acre-feet of ground water—19,000 from wells and 11,000 from Hot Creek Spring—is believed to be recoverable from the 53,000 acre-feet annually discharged from the valley by evapo-transpiration, underflow, and stream flow.

Artificial recharge to the ground-water reservoir is the practice of spreading surface water on areas of highly permeable sand

[11] "Beneficial use" is here construed to mean use involving a reasonable duty of water and may include natural losses between the point of diversion and the point of application.

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and gravel connected with the aquifers. This may be done during periods in which there is little or no use of the surface-water supply. Water spreading in many places, notably in southern California, has resulted in considerable conservation of water otherwise lost for beneficial use. It is unlikely that water spreading would prove feasible in White River Valley at present, because it would tend to increase the losses from evaporation and transpiration from the present areas with a shallow water table. However, should heavy pumping materially lower the water table in the vicinity of Preston and Lund, some relief may be afforded by water spreading in areas north and east of Preston. Water for such artificial recharge might be available from the winter discharge of Preston Big, Arnoldson, Cold, and Nicholas Springs, only part of which is now used. Further, unused winter discharge from Lund Spring might also be utilized for the same purpose in the vicinity of Lund.

QUALITY OF WATER

Chemical analyses of the waters from three springs in White River Valley are shown in Table 8. The analyses show that the waters discharged by these springs are moderately hard but low in mineral content. The water would be satisfactory for stock-watering, domestic, and irrigation use.

TABLE 8

Chemical analyses of the waters from three springs in White River Valley, Nevada

(Analyses in parts per million)

Chemical constituents	Spring (Name, Number, and Location)		
	Lund Spring[1] 11/62-4A1	Butterfield Springs[2] 7/62-28B1	Hot Creek Spring[1] 6/61-18A1
Silica (SiO_2)	13	46	32
Iron and Aluminum (Fe and Al)	..	0.3	
Calcium (Ca)	36	40	58
Magnesium (Mg)	24	23	22
Sodium and potassium (Na and K)	3.7	2	32
Bicarbonate (HCO_3)	276	178	294
Sulfate (SO_4)	13	27	45
Chloride (Cl)	3.0	18	12
Nitrate (NO_3)	3.2	---	0.3
Boron (B)	0.02	---	0.04
Dissolved solids	252	283	346
Hardness (as $CaCO_3$) Total	238	194	235
Specific conductance ($K \times 10^6$ at 25° C.)	445	---	564

[1]Analyses by Salt Lake City Laboratory of the U. S. Geological Survey. Samples collected May 27, 1949.

[2]Analysis by W. B. Adams (from chemical analyses of municipal water supplies, bottled mineral waters, and hot springs of Nevada: Univ. Nevada, Dept. Food and Drugs, Public Service Div., p. 16, 1944).

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It is believed that most of the waters from wells and springs in White River Valley are comparable in quality to the waters of the three springs mentioned above. Water from wells ranging from 20 to 80 feet in depth is used for domestic purposes throughout the valley and apparently is of satisfactory quality, for no objections to it were mentioned by the present local residents.

CONSTRUCTION OF WELLS

Wells with larger capacities would result from improved methods of well construction and development in White River Valley. Most of the wells in the valley are equipped either with perforated casing in which slots have been cut by the driller with a cutting torch before placing in the well, or with casing perforated with a casing ripper after the casing has been placed in the well. No wells have been equipped with well screens, nor have any been gravel-packed. Most of the wells only partially penetrate the water-bearing beds. So far as is known none of the irrigation wells have been fully developed by surging or other methods.

The slot area in the perforated casings in the wells range from about 1 to perhaps 10 percent of the surface area of the perforated parts of the casings, and the slots are relatively large openings that commonly allow both the coarse and the fine material of the water-bearing beds to enter the well. The width of the slots in perforated casing is the same or larger on the outside than it is on the inside of the casing, and the walls of the slots are rough and irregular. Thus, when the well is pumped much of the water-bearing material in the immediate vicinity of the well is drawn into the well and discharged through the pump. The beds overlying the water-bearing materials may be left unsupported and may collapse and clog the openings or crush the casing. The passage of the sand and gravel through the pump causes excessive wear on the working parts of the pump. The small proportion of slot area—the openings through which water must pass in order to enter the well—results in considerable loss in head through the screen—"screen loss"—and in lower specific capacity (yield per unit of drawdown) of the well. "Screen loss" also results from clogging in the rough, irregular slots.

Ideally a well as a hydraulic structure should be so designed as to admit with a minimum loss of head as much water as the water-bearing material can yield. That is, the permeability of the well structure should be as much as or greater than that of the

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water-bearing material. As the permeability of most aquifers is distributed about evenly throughout each square foot so, also, should the permeability of the well structure be distributed about evenly for each square foot of casing opposite the water-bearing material. Under such conditions, when the permeability of the well structure is as great as or greater than that of the water-bearing material, the maximum specific capacity can be obtained.

Ordinarily most of the loss of head in a well structure occurs where the water enters the casing. Thus to minimize the head loss or "screen loss" of a well structure it is desirable to provide sufficient openings in the well casing of such a size and distribution as to equal or yield in capacity the openings in the adjacent material. This may be done best by use of well screens and, where necessary, gravel packing.

Well screens commonly used for irrigation wells are designed with areas of slot openings that range from about 20 to 50 percent of the surface area of the screen. The percentage of slot area depends on the type of screen and the size of the slot openings. Commonly, samples of water-bearing materials are analyzed and the size of the slot opening is selected so that most of the fine-grained materials in the aquifer are removed during development of the well before the permanent pump is installed. The coarser materials are thus left in place, forming a wall of relatively permeable gravel and coarse sand around the well. The slots are wider on the inside of the screen so that particles will easily pass through the slots once they enter them. Thus the well-screen slots may be expected to remain open. These features of well screens result in larger yields and longer-lived wells.

Gravel-packed wells are constructed with a layer of gravel placed around the well casing or screen. The size of the gravel is selected so that the materials of the water-bearing beds will not pass through the gravels and into the well when water is pumped from it. The gravel-packed well is especially useful when the materials of the water-bearing beds are uniformly fine-grained. As the gravel pack reduces "screen loss" and prevents caving of the overlying beds, the gravel-packed well is commonly efficient and long-lived.

Complete penetration of the water-bearing beds by wells will also result in larger yields for each foot of drawdown. Many wells, regardless of how they are cased, will probably yield considerably more water if they are properly developed prior to the installation of the permanent pump.

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SUMMARY OF GROUND-WATER CONDITIONS

From the foregoing discussion the following conclusions may be drawn:

(1) The only source of ground water in White River Valley is precipitation on the tributary slopes of the Egan Range, White Pine Mountains, and Horse and Grant Ranges. Only a small part of this precipitation recharges the ground-water reservoir. Estimates based on the available precipitation data indicate that the annual recharge is approximately 53,000 acre-feet.

(2) Discharge of ground water from the valley occurs by transpiration from native and cultivated plants, evaporation, and surface and underground outflow. Estimates based on detailed data from other areas similar to White River Valley show that annual losses from evapo-transpiration are about 34,000 acre-feet. Stream flow and underflow from the south end of the valley are estimated to total about 19,000 acre-feet.

(3) About 12,000 acre-feet of ground water in White River Valley is estimated to be available by pumping in White Pine County, and 7,000 in Nye County. About 11,000 acre-feet may be made available by diverting the discharge of Hot Creek Spring.

(4) Artificial recharge to the ground-water reservoir may result in recovery of the wasted part of the winter discharge of the springs, if the water table is materially lowered by increased pumping in the vicinity of Preston and Lund.

(5) Logs and performance of wells drilled in the vicinity of Preston and Lund show that aquifers suitable for development of large-capacity wells are locally present in this area at depths ranging from 15 to 150 feet. Information from well records in other parts of the valley is either not available or inconclusive. However, surficial geologic and hydrologic evidence suggests that relatively permeable water-bearing beds may be present in the old river channel and on the lower parts of the alluvial fans. At favorable topographic locations, successful large-capacity wells could be developed from such aquifers.

RECONNAISSANCE LAND CLASSIFICATION

Development of ground water is expected to be initially for irrigation use in White River Valley. Because of this the Office of the State Engineer requested the Nevada Agricultural Experiment Station to make a land classification reconnaissance in the general area of potential ground-water development in White River Valley. The report by Howard G. Mason to Alfred Merritt Smith, State Engineer, is quoted below:

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"This survey was made in cooperation with the Nevada State Engineer and the Ground Water Branch of the U. S. Geological Survey. Its purpose is to indicate the location and approximate extent of potential agricultural land available for development by pumping from the ground waters in upper White River Valley.

"The land was classified on the basis of a field inspection of the surface and soil profile, where exposed, and the native vegetation. No laboratory work was done on the soils. Measurements were made by speedometer readings or pacing. The map was constructed on a base supplied by the Ground Water Branch. Ground control was limited, in part, to the topographic features present on the base map.

"The survey was limited to areas estimated to have ground water possibly available within a feasible pumping lift. This land was classified into three broad groups. Class I land is land which is considered to be definitely suitable for development so far as soil and topography are concerned. Class II land appears less definitely suitable, or is an intermixture of suitable and unsuitable land which was difficult to separate by this type of survey. Class III includes lands which were considered definitely unsuitable for development by the use of pumped water. The chief reason for placing lands in the lower grades was the expense involved in effecting complete reclamation by the use of pumped water.

"The land inspected is designated in four tracts for purposes of convenient description. Tract 1 is located on the floor of the main drainage way just east and northeast of Preston. This body of land has a deep, uniform, and permeable soil, free from harmful quantities of alkali or an excessive amount of calcium. The northern one-third of the tract has a rather uneven surface, and indications of some alkali in the subsoil. Tract 1 includes a gross area of about 2,500 acres.

"Tract 2 lies on the west side of the valley, beginning just south of the area irrigated by the Lund Spring, extending south into T. 8 N., R. 61 E., and including a small area south of Mormon Spring. This tract includes approximately 25,000 acres of mostly rather low-grade land. The bodies of what appeared to be good land were too small and irregular to be readily segregated by this type of survey. The major soil type is a dense clay which would be rather difficult to reclaim. Scattered over the tract are many irregular, more or less sandy areas. The most favorable sites for development are probably along the border between the sandy and clay soils. It is rather doubtful if many of these can

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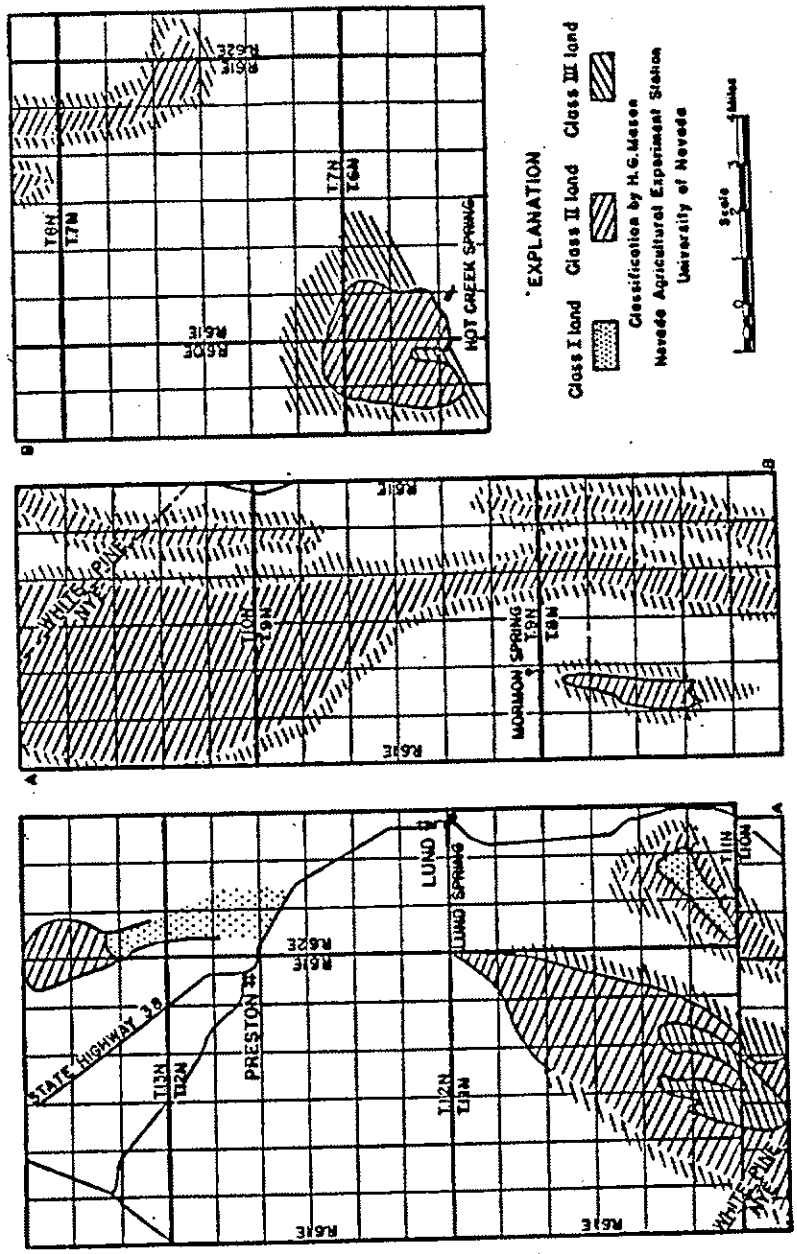

FIGURE 5—Reconnaissance classification of land in White River Valley, Nevada.

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be found which are large enough to be economically feasible. Several hundred acres in the north part of T. 10 and in the south part of T. 11 were placed in Class III because of the accumulation of an excessive amount of alkali.

"Tract 3 is located along the east side of the valley, south of Lund. It is on the toe of the alluvial slope from the Egan Range, and is possibly the most promising section of the valley. The soils generally are deep, permeable, and of medium texture. The best sites are located on gentle slopes, covered with a heavy growth of sage and rabbit brush, at an elevation of 10 feet or more above the transpiration area on the valley floor. There is a gross area of about 5,000 acres in Tract 3.

"Tract 4 includes land to the north and west which may be irrigated by gravity diversion of Hot Creek Spring, or by a low, pumping lift of these waters. The north and west boundaries of this tract was arbitrarily drawn to include about 3,500 acres. The same kind of land extends considerably farther north and west. This land lies well for irrigation, and in a compact body. The soil is medium to fine in texture, and highly calcareous. At a depth of from two to three feet the soil is so filled with lime concretions as to be impossible to bore with a soil augur. It is rather difficult to forecast how productive this land may be under irrigation. It will probably be much more productive at first than the land now being irrigated from Hot Creek Spring. The soil probably will respond rather well to applications of phosphate.

"A total area of approximately 36,000 acres was examined and classified as shown on Figure 5, page 52. Perhaps two-thirds of this land is of doubtful value for development by the use of pumped water. From the remainder, however, it should be possible to select sufficient reasonably good land on which to use all of the ground water which may be economically recovered in the area.

"HOWARD G. MASON,
"Nevada Agricultural Experiment Station."

WELL RECORDS

The following tables present the records of 98 wells in the valley. Table 9 shows the number, location, owner, type, diameter, and depth of each well. It also contains a list of all available measurements of the water levels in the wells, the principal use of water withdrawn from each well, and the type of pump and power used at each well. This table lists most of the known

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wells in the valley as of March 1948, and a few other wells, now destroyed, whose records have proved valuable in various phases of the investigation. All the wells in the table are shown on Plate 1 or Plate 2. Table 10 presents the 13 available logs and casing records for wells in the valley, and Figure 4 shows 6 of the logs graphically.

The wells and springs are identified by a numbering system based on the Mt. Diablo base and meridian network of surveys by the General Land Office. This numbering system also serves to locate the well or spring in the township, range, and section. The first unit, consisting of one or two numerals, is the township, and the second unit, consisting of two numerals, is the range; the entire area is in the northeast quadrant of the Mt. Diablo base and meridian, and the abreviations "N." and "E." are not used. The last unit, separated by a dash, shows the section, quarter section, and individual well number. Each section has been divided into four equal parts, each of which has been assigned a letter. Beginning with the northeast quarter, the letters have been assigned in a counterclockwise direction. Thus, the northeast quarter is A, the northwest quarter is B, the southwest quarter is C, and the southeast quarter is D. The first well recorded in a given quarter section is designated by the numeral 1, the second is designated by 2, and so forth. Thus, the first well located in the southeast quarter of section 31, Township 12 N., Range 62 E. would be numbered 12/62–31D1, the second well located would be numbered 12/62–31D2, and so forth. On Plates 1 and 2, only that part of the number designating the quarter section and the order in which the well or spring was recorded is shown.

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TABLE 9

Record of Wells in White River Valley, Nevada

(Type of well—B, bored; Dg, dug; Dr, drilled. Use of water—D, domestic; I, irrigation; N, not used; S, Stock; O, observation. Type of pump—C, cylinder; T, turbine; J, jet. Type of power—WM, windmill; F, fuel oil, gasoline, or diesel engine; H, horse; E, electric; W, water.)

Well number and location	Owner	Type of well and year completed	Diameter (inches)[1]	Depth (feet)	Measuring Point: Altitude above mean sea level datum (feet)	Measuring Point: Above (+) or below (−) land-surface (feet)	Measuring Point: Description	Water Level: Below measuring point (feet)	Water Level: Date	Use	Type of pump and power	Remarks
							NYE COUNTY					
5/59-32C1	Paris	Dr	6	.....	.....	+1.0	Bottom of hole in casing	9.01	2-27-48	S	C, WM	
8/60-28A1	Don Eldridge	Dr	6	142	.....	+2.5	Top of casing	118.70	2-27-48	S	C, F, WM	
9/60-1A1	Ernest Gubler	Dg	38	40	.....	.0	Top of casing	36.12	2-27-48	S	C, WM	
9/61-7B1	Lloyd Sorenson	Dg	48	43	.....	.0	Top edge of iron manhole	31.1	9-15-45	S	C, H	
								31.00	10-1-47			
								30.86	2-27-48			
10/60-13C1	Carter Bros. and others	Dr	6	.....	.....	+.5	Top of iron plate on casing	54.62	10-1-47	S	C, WM	
								55.19	2-27-48			
10/60-13C2	Carter Bros. and others	Dr, 1946	6	.....	.....	.....	.....	.....	.....	S	C, F	
10/60-24D1	Dan Clark	Dg	48	55	.....	+.5	Top of 2- by 4-inch upright	39.73	10-1-47	S	C, H	
								42.27	2-27-48			
10/60-36B1	Bureau of Land Management	Dr	8	.....	.....	+.5	Top of casing	42.07	10-1-47	S	J, F	Well cleaned. New pump installed Nov. 1947.
								41.90	2-27-48			
10/61-11D1		Dr	6	.....	.....	+.5	Top of iron place on casing	5.26	10-8-47	S	C, WM	
10/61-26B1	Carter Bros.	Dr	6	.....	.....	+.5	Bottom of hole in pump base	9.40	10-16-47	S	C, WM	
10/61-34A1	Don Eldridge	Dr	4	.....	.....	+2.5	Bottom of hole in pump base	8.56	10-16-47	S	C, WM	
							WHITE PINE COUNTY					
11/61-16D1	Carter Bros. and others	Dr, 1948	6	82	.....	+2.0	Top of casing	29.61	2-26-48	S	C, WM	
11/61-32B1	Carter Bros. and others	Dg	34	48	.....	+1.0	Top of casing and concrete curb	40.44	7-25-47	S	C, WM	
								40.60	10-29-47			
11/61-35A1		Dr	6	.....	.....	+0.5	Bottom of hole in pump base	13.02	9-9-47	S	C, WM	
								13.10	10-30-47			
11/61-35D1		Dg	66	17.1	.....	+3.0	Top of wood curb	16.90	8-15-45	S	C, WM	
11/62-4B1	Latter Day Saints Church	Dg	60	55	.....	+1.5	Top of 3- by 12-inch plank well cover	48.31	7-23-47	I	C, WM	
								44.99	3-29-48			
11/62-5A1	Vern Whipple	Dg	36	36	.....	+1.5	Top of concrete curb	34.26	7-23-47	S	C, WM	
								31.97	3-29-48			
11/62-5D1		Dr	6	30	.....	+1.5	Top of casing	7.60	7-23-47	S	C, WM	
								4.67	3-29-48			
11/62-6A1		Dg	28	10	5,507.16	+3.0	Top of casing	8.04	7-25-47	S	C, WM	
11/62-6D1		Dr	6	12	5,490.95	+.5	Top of iron plate on casing	6.64	10-8-47	S	C, WM	
11/62-6D2		Dr	6	.....	5,489.74	+1.0	Top of casing	5.17	10-8-47	S	C, WM	
11/62-7B1	Ernest Gubler	Dr	6	.....	.....	+1.0	Top of iron plate on casing	19.40	9-9-47	S	C, WM	
11/62-17C1	George Fawcett	Dg	60	15	.....	+1.0	Top of plank well cover	10.50	7-23-47	S	C, WM	
								8.08	3-29-48			
11/62-19C1		Dr	6	.....	.....	+1.0	Top of iron plate on casing	5.20	10-8-47	S	C, WM	
11/62-33D1	Merrill Gubler	Dr, 1948	14	130	.....	.0	Land surface	7	8-31-48			Casing pulled, well abandoned. Log.
12/60-11A1	Nevin Munson	Dg	48	20.5	.....	+2.0	Top of 8- by 8-inch timber cribbing	18.10	12-1-47	N		
12/61-2C1	Lloyd Oxborrow	Dr	10.8	170	.....	.....	Flowing	.....	7-17-47	I		
12/61-12D1	Mrs. Berinson	Dg	48	69.5	5,618.28	+.5	Top of plank cover	64.83	7-18-47	N	C, WM	
								65.52	10-28-47			
12/61-12D2	H. Whitlock and others	Dg	60	70	.....	.....	.....	.....	.....	D	C, W	

[1]The maximum width of square or rectangular dug wells is given in place of diameter. Diameter is given for top of casing or at land surface.

"BEST AVAILABLE COPY"

TABLE 9—*Continued*

Well number and location	Owner	Type of well and year completed	Diameter (inches)[1]	Depth (feet)	Measuring Point: Altitude above mean sea level datum (feet)	Measuring Point: Above (+) or below (−) land-surface (feet)	Measuring Point: Description	Water Level: Below measuring point (feet)	Water Level: Date	Use	Type of pump and power	Remarks
1-12D3	Preston School	Dr	6	----	----	----	----	----	----	N		
1-12D4	Lowell Peterson	Dr	6	----	----	+.5	Bottom of hole in pump base	61.24	10- 1-47	N	C, H	
								61.67	10-23-47			
1-12D5	Lowell Peterson	Dr	----	----	----	----	----	----	----	D	J, E	
1-13A1	John Dennis	Dg	48	72	5,616.65	+.5	Top of plank cover	67.12	7-28-47	D	C, WM	
								68.20	10-23-47			
								67.20	11-24-47			
1-13D1	Lowell Peterson	Dr, 1919	12	184	----	−2.0	Top of casing	56.27	12-12-47	N	—	Log. Reported depth 560 feet.
1-13D2	Lowell Peterson	Dr, 1919	—	—	----	—	----	----	----	—	—	Destroyed.
1-34A1	Bureau of Land Management	Dr	7	----	----	+1.5	Top of casing	59.56	7-15-47	S	C, WM	
								59.80	10-29-47			
2-6D1		Dr, 1916	72	1,300	----	----	----	60.00	3-29-48	—	—	Log. Well destroyed.
2-17D1	Peacock Bros.	Dr	6	----	----	+1.5	Bottom of hole in pump base	58.46	9-30-47	S	C, WM	
								58.74	10-28-47			
2-17D2	Eugene Peacock	Dr, 1947	6	74	----	----	----	----	----	S	C, WM	Log.
2-18D1	U. S. Geological Survey	Dr, 1947	6	108	----	+.5	Top of casing	51.23	12-18-47	O	—	Log.
								44.41	3-26-48			
2-19B1	Mrs. Berinson	Dr	6	54	5,574.29	+1.0	Top of iron plate on casing	43.57	7-17-47	S	C, WM	
								44.55	10- 8-47			
								44.62	11-24-47			
2-20B1	A. N. Carter	Dg	60	32	5,560.61	.0	Top of 3- by 2-inch plank cover	29.06	7-22-47	N	C, WM	
								29.76	11-24-47			
								30.28	3-28-48			
2-20B2	W. M. Reid	Dr, 1948	16	107	----	+1.0	Top of casing	26.44	1- 5-48	I	T, F	Log.
								26.52	3-30-48			
2-20C1	A. N. Carter	Dg	72	31	----	.0	Top of concrete curb	29.46	12-18-47	N		
								30.65	3-26-48			
2-20D1	A. N. Carter	Dg	48	34	5,556.14	+.5	Top of 2- by 12-inch plank cover	28.88	7-17-47	S	C, WM	
								28.85	11-25-47			
2-28B1	Delile Terry	Dr	6	60	5,575.96	+1.0	Bottom of hole in pump base	43.77	12-12-47	D	C, WM	
2-28C1	Delile Terry	Dr	6	----	5,556.12	+1.0	Bottom of hole in pump base	44.75	10- 8-47	S	C, WM	
2-28C2	Joe Vance	Dg	24	32	5,554.01	+1.5	Top of casing	27.12	7-22-47	S	C, WM	
								24.54	12-12-47			
2-29A1	James Oxborrow	Dr	6	...	5,546.79	+.5	Top of casing	20.66	7-17-47	S	C, WM	
2-29B1	Kenneth Gubler	Dr	14	112	5,552.5	+.5	Lower lip of pump discharge pipe	30.84	7-17-47	I	T, F	Log.
2-29D1	Delile Terry	Dr	6	50	5,537.72	+.5	Bottom of hole in pump base	15.26	10- 8-47	S	C, WM	
								14.80	12-12-47			
2-29D2	James Oxborrow	Dr	6	----	5,538.08	.0	Bottom of hole in pump base	16.63	10- 8-47	S	C, WM	
								16.70	12-12-47			
2-29D3		Dg	60	16	5,533.10	+1.5	Top of concrete curb	12.29	7-22-47	S	C, WM	
								13.89	----			
2-30A1	Leland Hendrix	Dr	6	----	----	----	----	----	----	S	C, WM	
2-30A2	Peacock Bros.	Dr	6	----	5,546.69	.0	Bottom of hole in pump base	27.02	9-30-47	S	C, WM	
2-30B1	Peacock Bros.	Dr	6	----	5,558.40	+0.5	Bottom of hole in pump base	37.75	9- 9-47	S	C, WM	
								35.83	11-25-47			
2-30B2	Peacock Bros.	Dr	6	----	5,545.33	+.5	Bottom of hole in pump base	26.83	9-30-47	S	C, WM	
2-30C1	Peacock Bros.	Dr	6	50	----	+1.0	Bottom of hole in pump base	22.94	9-30-47	S	C, WM	
2-30D1	W. A. Reed	Dg	48	----	5,531.66	.0	Top of concrete curb	15.06	7-16-47	S	C, WM	
2-30D2		Dr	6	32	5,537.48	+1.0	Top of casing	20.50	7-22-47	S	C, WM	

[1]The maximum width of square or rectangular dug wells is given in place of diameter. Diameter is given for top of casing or at land surface.

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TABLE 9—Co

Well number and location	Owner	Type of well and year completed	Diameter (inches)[1]	Depth (feet)	Measuring Point: Altitude above mean sea level datum (feet)	Measuring Point: Above (+) or below (−) land-surface (feet)	Measuring Point: Description	Water Level: Below measuring point (feet)	Water Level: Date	Use	Type of pump and power	Remarks
-12D3	Preston School	Dr	6	----	----	----		----	----	N		
-12D4	Lowell Peterson	Dr	6	----	----	+.5	Bottom of hole in pump base	51.24	10- 1-47	N	C, H	
								61.67	10-28-47			
-12D5	Lowell Peterson	Dr	----	----	----	----		----	----	D	J, E	
-13A1	John Dennis	Dg	48	72	5,616.65	+.5	Top of plank cover	67.12	7-22-47	D	C, WM	
								68.20	10-28-47			
-13D1	Lowell Peterson	Dr, 1919	12	184	----	—2.0	Top of casing	67.20	11-24-47			
-13D2	Lowell Peterson	Dr, 1919	----	----	----	----		56.27	12-12-47	N	—	Log. Reported depth 560 feet.
-34A1	Bureau of Land Management	Dr	7	----	----	+1.5	Top of casing	----	----	---	—	Destroyed.
-5D1		Dr, 1916	7[1]	1,300	----			59.56	7-15-47	S	C, WM	
-17D1	Peacock Bros.	Dr	6	----	----	+1.5	Bottom of hole in pump base	59.80	10-23-47			
								60.00	3-23-48	—	—	Log. Well destroyed.
-17D2	Eugene Peacock	Dr, 1947	6	74	----			58.45	9-30-47	S	C, WM	
-18D1	U. S. Geological Survey	Dr, 1947	6	108	----	+.5	Top of casing	58.74	10-23-47			
-19B1	Mrs. Berinson	Dr	6	54	5,574.29	+1.0	Top of iron plate on casing	51.23	12-12-47	S	C, WM	Log.
								44.41	3-30-48	O	—	Log.
-20B1	A. N. Carter	Dg	60	32	5,560.61	.0	Top of 2- by 2-inch plank cover	43.57	7-17-47	S	C, WM	
								44.55	10- 2-47			
								44.62	11-24-47			
-20B2	W. M. Reid	Dr, 1948	16	107	----	+1.0	Top of casing	29.06	7-22-47	N	C, WM	
								29.76	11-24-47			
-20C1	A. N. Carter	Dg	72	31	----	.0	Top of concrete curb	30.22	3-30-48			
								36.44	1- 5-48	I	T, F	Log.
-20D1	A. N. Carter	Dg	48	24	5,556.14	+.5	Top of 2- by 12-inch plank cover	36.52	3-30-48			
								29.46	12-12-47	N		
								30.65	3-30-48			
-28B1	Delile Terry	Dr	6	60	5,575.96	+1.0	Bottom of hole in pump base	28.88	7-17-47	S	C, WM	
								28.85	11-25-47			
-28C1	Delile Terry	Dr	6	----	5,556.12	+1.0	Bottom of hole in pump base	43.77	12-12-47	D	C, WM	
-28C2	Joe Vance	Dg	24	33	5,554.01	+1.5	Top of casing	44.75	10- 8-47	S	C, WM	
-29A1	James Oxborrow	Dr	6	----	5,546.79	+.5	Top of casing	27.12	7-22-47	S	C, WM	
-29B1	Kenneth Gubler	Dr	14	112	5,552.5	+.5	Lower lip of pump discharge pipe	24.54	12-12-47			
-29D1	Delile Terry	Dr	6	50	5,537.72	+.5	Bottom of hole in pump base	20.66	7-17-47	S	C, WM	
								20.84	7-17-47	I	T, F	Log.
-29D2	James Oxborrow	Dr	6	----	5,538.08	.0	Bottom of hole in pump base	15.26	10- 8-47	S	C, WM	
								14.80	12-12-47			
-29D3		Dg	60	16	5,533.10	+1.5	Top of concrete curb	16.68	10- 2-47	S	C, WM	
								16.70	12-12-47			
-30A1	Leland Hendrix	Dr	6	----	----	----		12.39	7-22-47	S	C, WM	
-30A2	Peacock Bros.	Dr	6	----	5,546.69	.0	Bottom of hole in pump base	13.89	----	S	C, WM	
-30B1	Peacock Bros.	Dr	6	----	5,558.40	+0.5	Bottom of hole in pump base	27.02	9-30-47	S	C, WM	
-30B2	Peacock Bros.	Dr	6	----	5,545.23	+.5	Bottom of hole in pump base	37.75	9- 9-47	S	C, WM	
-30C1	Peacock Bros.	Dr	6	50	----	+1.0	Bottom of hole in pump base	35.83	11-25-47			
-30D1	W. A. Reed	Dg	48	----	5,531.66	.0	Top of concrete curb	26.83	9-30-47	S	C, WM	
-30D2		Dr	6	32	5,537.48	+1.0	Top of casing	22.94	9-30-47	S	C, WM	
								15.06	7-16-47	S	C, WM	
								20.50	7-22-47	S	C, WM	

[1]The maximum width of square or rectangular dug wells is given in place of diameter. Diameter is given for top of casing or at land surface.

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TABLE 9—*Continued*

Well number and location	Owner	Type of well and year completed	Diameter (inches)[1]	Depth (feet)	Measuring Point: Altitude above mean sea level datum (feet)	Measuring Point: Above (+) or below (−) land-surface (feet)	Measuring Point: Description	Water Level: Below measuring point (feet)	Water Level: Date	Use	Type of pump and power	Remarks
12/62-30D3		Dr	6	----	5,535.28	+.5	Top of casing	18.66	7-22-47	S	C, WM	
12/62-30D4	Peacock Bros.	Dr	6	----	5,535.72	+1.0	Bottom of hole in pump base	18.92	9-30-47	S	C, WM	
12/62-31A1	Milton Gardner	Dg	48	15	----	+1.0	Top of plank cover at pump base	10.50	7-18-47	S	C, WM	
								11.20	11-30-47			
12/62-31A2		Dg	48	18	5,520.48	+.5	Top of plank cover	13.80	7-25-47	S	C, WM	
								13.77	10-29-47			
12/62-31D1	Carter Bros.	Dr, 1941	16	178	5,517.87	+1.5	Top of hole in pump base	13.53	9-15-46	I	T, F	Log. 6-inch hole 65 to 178 feet in Feb. 1948; 6-inch casing pulled.
								13.88	7-16-47			
								14.66	10-29-47			
								14.53	12- 2-47			
								13.42	2-18-48			
12/62-31D2	Carter Bros.	Dg	48	16	5,516.75	+.5	Top of plank cover	12.95	7-18-47	S	C, WM	
								13.10	10-29-47			
								12.28	12- 2-48			
12/62-31D3	Carter Bros.	Dr, 1948	16	128	5,516.28	+1.0	Top of casing	12.30	2-18-48	I	T, F	Log.
12/62-32A1	Carter Bros.	Dr	6	----	5,538.70	+.5	Bottom of hole in pump base	9.64	12-12-47	S	C, WM	
12/62-32B1	Cannon Gardner	Dr	6	----	5,520.57	+.5	Bottom of hole in pump base	7.50	9-30-47	S	C, WM	
12/62-32B2	Cannon Gardner	B, 1943	3	12	----	+.5	Top of casing	7.85	1-22-48	S	C, WM	
12/62-32C1	Cannon Gardner	Dr	4	----	----	+.5	Bottom of hole in pump base	6.05	10-29-47	S	C, WM	
12/62-33A1	G. M. Reid	Dg	60	48	5,594.03	+1.5	Top of 2- by 4-inch curb	41.91	7-23-47	S	C, WM	
								41.96	11- 6-47			
12/62-33A2	Cliff Peacock	Dr	6	----	5,593.35	+.5	Hole in pump base	40.20	7-23-47	S	C, WM	
12/62-33A3	Maurice Oxborrow	Dg	48	46	5,590.65	+1.5	Top of concrete curb	37.64	7-23-47	S	C, WM	
								36.60	11- 6-47			
12/62-33A4	Clinton Scow	Dr	6	52	5,593.47	+.5	Top of casing	39.12	7-23-47	N	C, WM	
								38.80	11- 6-47			
12/62-33A5	Wayne Gardner	Dg	48	31	5,578.95	+.5	Top of edge of iron manhole	20.30	7-23-47	D	C, WM	
								19.89	11- 6-47			
12/62-33A6	Vance McKenzie	Dg	---	----	5,598.18	+0.5	Top of plank well cover	39.82	7-23-47	D	J, E	
								40.40	11- 6-47			
12/62-33A7	Lorraine Hendrix	Dg	48	35	5,591.83	+2.0	Top of manhole	32.71	7-23-47	S	C, WM	
								32.72	11-20-47			
12/62-33A8	Loren O'Donnell	Dr	6	----	5,594.18	+.5	Top of casing	33.02	7-23-47	S	C, WM	
								33.07	11-20-47			
12/62-33A9	Milton Gardner	Dg	48	23	5,562.99	.0	Top of concrete curb	16.69	7-23-47	N	C, WM	
12/62-33B1		Dr	6	----	5,527.43	+1.0	Top of iron plate on casing	7.71	9-30-47	S	C, WM	
								5.97	11-20-47			
12/62-33B2		Dr	6	----	5,532.30	.0	Top of iron plate on casing	10.07	10- 9-47	S	C, WM	
								9.18	11-20-47			
12/62-33B3	Delile Terry	Dr	6	----	5,533.00	+.5	Top of iron plate on casing	7.32	10-13-47	S	C, WM	
								7.37	11-20-47			
12/62-33C1		Dg	24	9.5	5,543.43	+2.5	Top of casing	3.54	7-23-47	S	C, WM	
12/62-33C2		Dr	6	14.5	----	+2.0	Top of casing	3.72	10-29-47	S	C, WM	
12/62-33D1	Doyle Wakely	Dr	6	----	----	+.5	Top of casing	24.00	7-23-47	D	C, WM	
12/62-33D2	Leland Hendrix	Dr	6	----	----	----	----	----	----	D	J, E	
12/62-33D3	Wilfred Terry	Dr	6	225	----	+.5	Edge of lower lip of 1-inch ell	6.75	7-23-47	D	C, WM	
12/62-33D4	Delile Terry	Dr	6	----	5,556.17	.0	Top of iron plate on casing	----	----	D	C, WM	
12/62-33D5	Ervin Hendrix	Dr, 1947	6	----	----	−3.5	Top of casing	6.50	12-11-47	D	---	
12/62-33D6	Ervin Hendrix	Dr	6	----	----	+1.0	Top of casing	13.55	12-11-47	N	---	
12/62-33D7	Vance Smith	Dr, 1948	6	99	----	+1.5	Top of casing	6.57	2-22-48	D	----	Log.
13/61-9C1	William Wieser	Dr, 1948	6	190	----	+1.0	Top of casing	----	----	D	C, WM	Log.
13/61-25A1	Bureau of Land Management	Dg	72	36.5	----	.0	Top of wood crib	35.32	12-12-47	N	---	
								35.26	1- 5-48			
								35.07	3-29-48			
14/59-26A1	Jesse Gardner	B	36	60	----	----	----	----	----	D	C, WM	
14/61-9C1	Bureau of Land Management, Jakes Wash well	Dr, 1938	6	365	6,150 (Estimated)		Land surface	350±	1938	S	C, WM	Water level reported by driller.
14/62-31B1	Bureau of Land Management	Dr, 1938	6	185	----	+5.5	Top of casing—dry at	182 ft.	7-25-47	N	---	Log. Abandoned.
14/62-31B2	Bureau of Land Management	Dr, 1938	6	145	----	----	Land surface—dry at	145 ft.	1938	N	---	Log. Abandoned.

[1]The maximum width of square or rectangular dug wells is given in place of diameter. Diameter is given for top of casing or at land surface.

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TABLE 10

Logs and casing records of wells in White River Valley, Nevada

11/62-33D1. Merrill Gubler. Diameter, 14 inches to 130 feet. Casing pulled and well abandoned. Driller's log.

Material	Thickness (feet)	Depth (feet)
Clay	11	11
Gravel; water rose 4 feet in casing	2	13
Cemented gravel	3	16
Soft clay	19	35
Cemented gravel	5	40
Clay, some gravel	59	99
"Hardpan" (lime)	3	102
Yellow clay	3	105
"Hardpan" (lime)	2	107
Blue clay	0.5	107.5
Yellow clay	18.5	126
"Hardpan" (lime)	4	130
Yellow clay	...	130
Total depth	...	130

12/61-13D1. Lowell Peterson. Diameter, 12 inches to 20 feet, 9⅝ inches from 20 to 117 feet, 7⅝ inches from 117 to 487 feet; uncased from 487 to 560 feet. Driller's log from county records. Well abandoned.

Material	Thickness (feet)	Depth (feet)
Soil	5	5
Gravel	15	20
Clay, yellow	5	25
Gravel	15	40
Gravel and sand	30	70
(Water level 70 feet below land surface)		
Sand	30	100
Gravel	10	110
Sand and gravel	50	160
"Rock"	5	165
Sand	10	175
Clay and sand	20	195
Clay, yellow	25	220
(Water level 85 feet below land surface)		
Sand	10	230
Sand and clay, yellow	40	270
Clay and sand, white	10	280
Clay and sand, yellow	10	290
Gravel, cemented	25	315
Clay, "gumbo," yellow to white	13	328
Sand, fine, black	7	335
Clay, yellow	3	338
Sand, fine, black	10	348
Sand, dark	7	355
Clay, yellow	1	356
Sand, dark	2	358
Sand	22	380
Sand to mud, yellow	5	385
Sand to mud, white	30	415
"Talc," white	20	435
Mud, white, soft	15	450
Mud, gray, soft	5	455
Clay, pink, soft	5	460
Clay, yellow, soft	10	470
Clay and sand, gray, soft	45	515
"Gumbo," gray, soft	20	535
Clay, yellow, soft	25	560
Total depth	...	560

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12/62–5D1. Data of uncertain value. Diameter, 7⅝ inches to 1,226 feet. Driller's log from county records. Well destroyed.

Material	Thickness (feet)	Depth (feet)
Gravel	45	15
Soft muddy formation	7	52
Gravel (water struck at 115 feet)	123	175
Sand	65	240
Gravel, hard	8	248
Sand	32	280
"Hard streak"	10	290
Gravel	No record	
Sand and gravel	No record	
Sand and gravel	110	500
Clay and gravel	40	540
Clay, little sand	460	1,300
Total depth	----	1,300

12/62–17D2. Eugene Peacock. Diameter, 6 inches to 74 feet; casing perforated with 5/16- by 3-inch slots, four to the round, one round to the foot. Driller's log.

Material	Thickness (feet)	Depth (feet)
Clay and gravel	6	6
Clay, sandy	10	16
Sand and gravel	5	21
Clay, sandy, cemented	3	24
Clay, sandy	3	27
Clay, sandy, cemented	12	39
Clay, sandy, soft; little water	22	61
Clay, sandy, cemented	6	67
"Hardpan" (lime)	1	68
Sand and gravel; water	6	74
Total depth	----	74

12/62–18D1. U. S. Geological Survey. Test well drilled by Lund Irrigation District. Land-surface altitude, 5,577 feet. Diameter, 6 inches to 105 feet; open end, not perforated. Driller's log.

Material	Thickness (feet)	Depth (feet)
Top soil	3	3
Clay, sandy, cemented	15	18
Clay, sandy, soft, wet	13	31
Clay, sandy, cemented	4	35
Clay, sandy, soft	14	49
"Hardpan"	1	50
Clay, sandy, soft	17	67
Sand, fine	6	73
(Water rose 19 feet)		
Clay, soft	7	80
Sand, coarse, water	11	91
Clay, soft	8	99
Sand, coarse	6	105
Clay, sandy, soft	3	108
Total depth	----	108

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12/62-20B2. W. M. Reid. Irrigation well; diameter, 16 inches to 107 feet; casing perforated with Mills Knife ½ by 3-inch slots, 13 to the round, 51 rounds on 1 foot centers. Driller's log.

Material	Thickness (feet)	Depth (feet)
Soil, black	19	19
Gravel and clay, cemented	10	29
Clay, sandy	9	38
Clay, sandy, cemented	4	42
Gravel, coarse, and sand	5	47
(Water level rose 10 feet to 32 feet)		
Clay, gravelly, cemented	5	52
Sand and gravel; water	10	62
Clay, sandy, cemented	11	73
Sand and gravel; water	2	75
Clay and gravel	2	77
Sand and gravel; water	2	79
Clay and gravel	3	82
Clay, yellow	7	89
Clay, sandy, cemented	3	92
Sand and coarse gravel; water	15	107
Total depth	—	107

12/62-29B1. Kenneth Gubler. Land-surface altitude, 5,553 feet. Irrigation well; diameter, 14 inches to 112 feet; yield, about 1,100 gallons a minute. Log from Soil Conservation Service.

Material	Thickness (feet)	Depth (feet)
Soil, black	2	2
Clay, yellow	36	38
Gravel and sand; water	12	50
Clay, yellow	25	75
Sand and gravel, hard, cemented	5	80
Clay, sandy, yellow	12	92
Sand and gravel, hard, cemented	8	100
Gravel and sand; water	10	110
Clay, blue	2	112
Total depth	—	112

12/62-31D1. Carter Bros. Land-surface altitude 5,516 feet. Irrigation well; diameter, 16 inches to 65 feet, 6 inches from 65 to 178 feet; 16-inch casing perforated with ⅛- to ¼-inch slots, about two per linear foot from 13 to 60 feet; 6-inch casing removed from well. Yield, about 500 gallons a minute. Driller's log.

Material	Thickness (feet)	Depth (feet)
Soil, clay; water at 12 feet	18	18
Clay	1	19
Gravel, cemented	5	24
Gravel; water	5	29
Clay	2	31
Sand and gravel	6	37
"Lime-cemented" material	1	38
Clay	2	40
Sand and gravel	3	43
"Cemented lime"	1	44
Clay	2	46
Gravel	5	51
"Cemented lime"	1	52
Clay	2	54
Gravel	3	57
Clay	3	60
Gravel	5	65
Clay, sandy	15	80
Sand and gravel	1	81
Clay, sandy	35	116
"Hardpan"	1	117
Clay, sandy	19	136
Sand and gravel, "muck"; water	6	142
Clay, sandy	36	178
Total depth	—	178

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12/62-31D3. Carter Bros. Land-surface altitude 5,515 feet. Irrigation well; diameter, 16 inches to 128 feet; 94 feet of 16-inch casing; perforated from 12 to 30 feet, 31 to 36 feet, and 40 to 44 feet with ½- by 3-inch slots, 13 to the round with rounds on 8-inch centers. Driller's log.

Material	Thickness (feet)	Depth (feet)
Black soil	13	13
Boulder gravel, sand and small gravel; water	16	29
Clay, sandy	3	32
Sand and gravel; water	3	35
Clay and gravel	6	41
Sand and gravel; water	2	43
Clay, sandy	19	62
"Hardpan" (lime)	1	63
White clay	24	87
Clay, sandy, cemented	5	92
Sand, black, coarse- to medium-grained; water	2	94
Clay, sandy, cemented	6	100
Clay, sandy, yellow	28	128
Gravel, coarse, and sand	---	128
Total depth	---	128

12/62-33D7. Vance Smith. Diameter, 6 inches to 99 feet; 6-inch casing to 87 feet, perforated with 5/16- by 3-inch slots from 67 to 87 feet. Driller's log.

Material	Thickness (feet)	Depth (feet)
Clay	18	18
"Hardpan" (lime)	4	22
Clay	32	54
"Hardpan" (lime); little water	2	56
Clay	43	99
Gravel; water level in casing rose 91 feet	---	99
Total depth	---	99

13/61-9C1. William Wieser. Diameter, 6 inches. Driller's log.

Material	Thickness (feet)	Depth (feet)
Soil	2	2
White rhyolite	78	80
Decomposed rhyolite and silt; little water	10	90
White rhyolite	90	180
Decomposed rhyolite and silt; little water	1	181
White rhyolite	8	189
Brown "loose" sand; water level rose 121 feet	1	190
Total depth	---	190

14/62-31B1. Bureau of Land Management. Diameter, 6 inches; 169 feet of casing. Driller's log.

Material	Thickness (feet)	Depth (feet)
"Earth" and gravel	3	3
Sandstone, hard, white	27	30
Sandstone, soft, white, and clay	3	33
Sandstone, hard, brown	13	46
Sandstone, hard, white	28	74
Sandstone, hard, brown	18	92
Sandstone, "medium," white	10	102
Sandstone, "medium," brown, and clay	42	144
Clay and sand, soft, brown	17	161
Sandstone, "medium," white	9	170
Sandstone, hard, white	15	185
("Water indications" at 185 feet)		
Total depth	---	185

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14/62–31B2. Bureau of Land Management. Diameter, 6 inches. Well abandoned.

Material	Thickness (feet)	Depth (feet)
"Earth" and gravel	5	5
Sandstone, hard, brown	35	40
Clay, brown	3	43
Sand and gravel; "seepage water"	37	80
Sand, black, and clay	15	95
Sand, fine	6	101
Sand, black, and clay	27	128
Limestone, "medium," white	10	138
Clay, gravel to "limestone"	7	145
(Lost shoe in hole; well abandoned)		
Total depth	—	145

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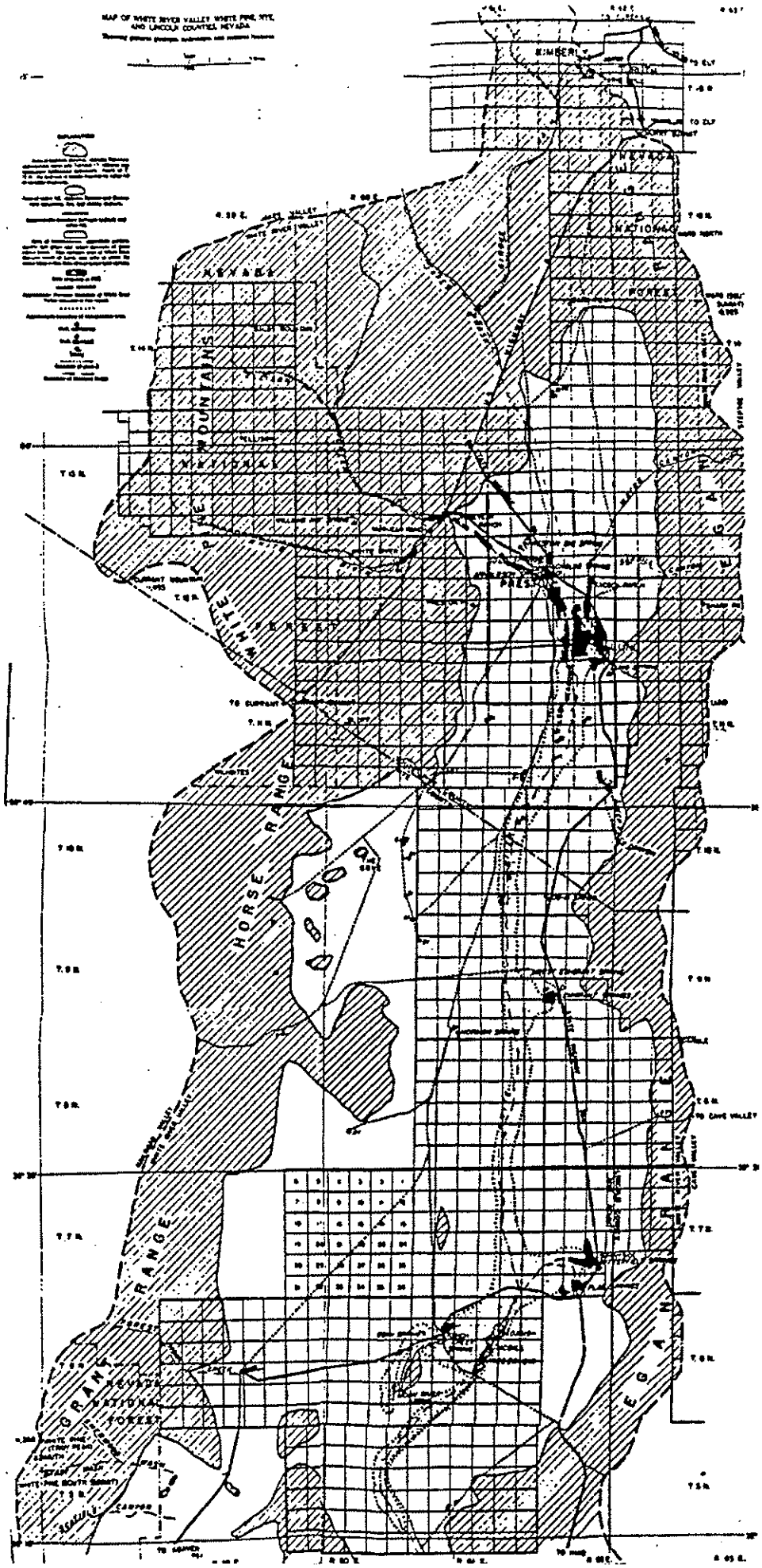

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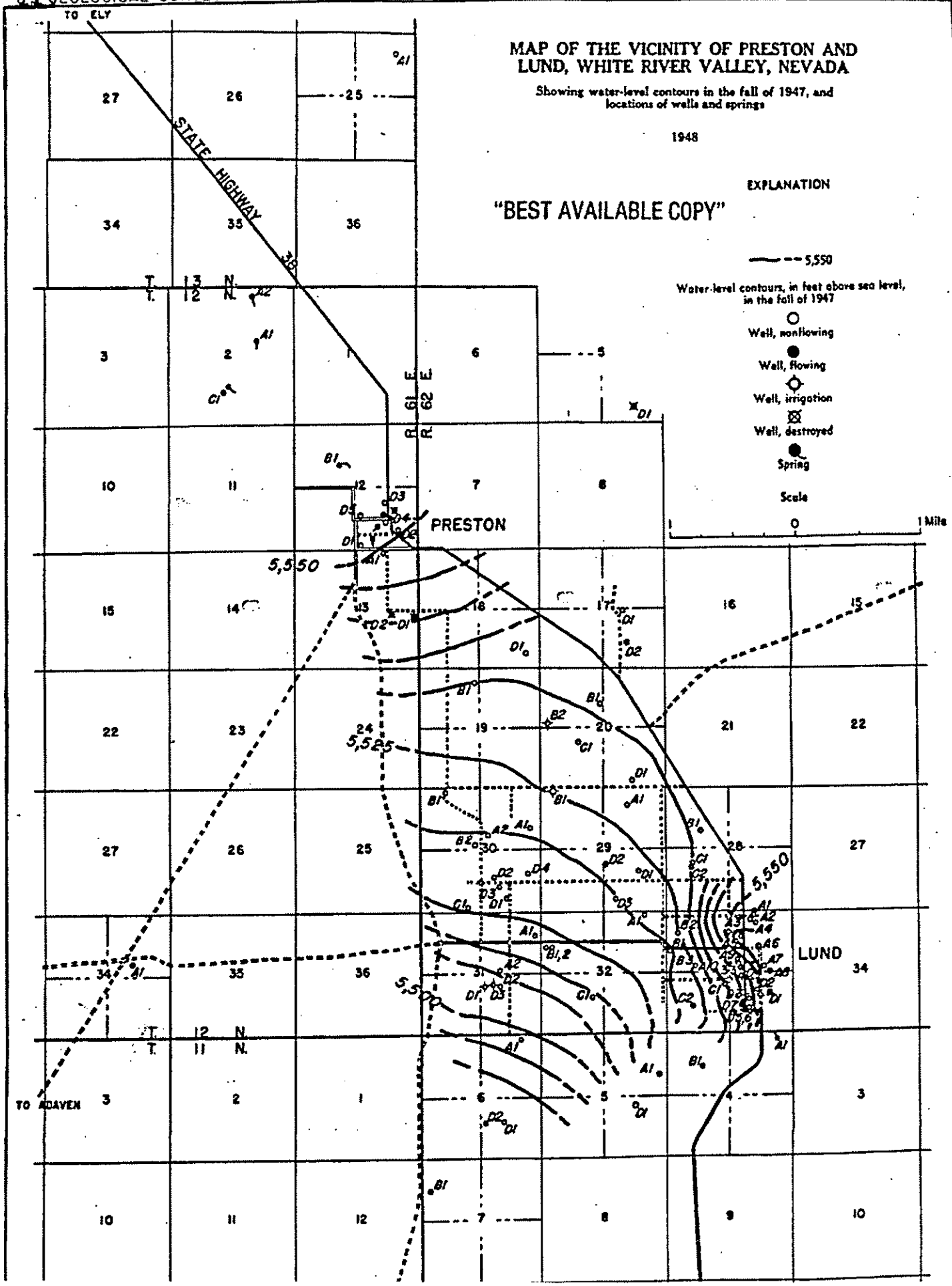
MAP OF THE VICINITY OF PRESTON AND LUND, WHITE RIVER VALLEY, NEVADA
Showing water-level contours in the fall of 1947, and locations of wells and springs
1948
EXPLANATION
5,550
Water-level contours, in feet above sea level, in the fall of 1947
Well, nonflowing
Well, flowing
Well, irrigation
Well, destroyed
Spring
Scale
1 0 1 Mile
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TO ELY
STATE HIGHWAY 35
T. 13 N.
T. 12 N.
R. 61 E.
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PRESTON
LUND
5,550
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ENCLOSURE

#6

SECTION 3

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ESTIMATES OF GROUND-WATER RECHARGE RATES FOR TWO SMALL BASINS IN CENTRAL NEVADA

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 94-4104

Prepared in cooperation with the
NEVADA OPERATIONS OFFICE,
U.S. DEPARTMENT OF ENERGY under
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Denver, Colorado
1995

U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

Gordon P. Eaton, Director

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
calorie (cal)	4.184	joule
centimeters per year (cm/yr)		
cubic meter per second (m^3/s)	0.02832	cubic foot per second
meter (m)	0.3048	foot
millimeter (mm)	25.4	inch
kilometer (km)	1.609	mile
square kilometer (km^2)	2.590	square mile

Degree Celsius (°C) may be converted to degree Fahrenheit (°F) by using the following equation:

$$°F = 9/5\ (°C) + 32.$$

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Estimates of Ground-Water Recharge Rates for Two Small Basins in Central Nevada

By Robert W. Lichty *and* Patrick W. McKinley

Abstract

Estimates of ground-water recharge rates developed from hydrologic modeling studies are presented for 3-Springs and East Stewart basins, two small basins (analog sites) located in central Nevada. The analog-site studies were conducted to aid in the estimation of recharge to the paleohydrologic regime associated with ground water in the vicinity of Yucca Mountain under wetter climatic conditions. The two analog sites are located to the north and at higher elevations than Yucca Mountain, and the prevailing (current) climatic conditions at these sites is thought to be representative of the possible range of paleoclimatic conditions in the general area of Yucca Mountain during the Quaternary. Two independent modeling approaches were conducted at each of the analog sites using observed hydrologic data on precipitation, temperature, solar radiation, stream discharge, and chloride-ion water chemistry for a 6-year study period (October 1986 through September 1992). Both models quantify the hydrologic water-balance equation and yield estimates of ground-water recharge, given appropriate input data. The first model uses a traditional approach to quantify watershed hydrology through a precipitation-runoff modeling system that accounts for the spatial variability of hydrologic inputs, processes, and responses (outputs) using a daily computational time step. The second model is based on the conservative nature of the dissolved chloride ion in selected hydrologic environments, and its use as a natural tracer allows the computation of a coupled, water and chloride-ion, mass-balance system of equations to estimate available water (sum of surface runoff and ground-water recharge).

Results of the modeling approaches support the conclusion that reasonable estimates of average-annual recharge to ground water range from about 1 to 3 centimeters per year for 3-Springs basin (the drier site), and from about 30 to 32 centimeters per year for East Stewart basin (the wetter site). The most reliable results are those derived from a reduced form of the chloride-ion model because they reflect integrated, basinwide processes in terms of only three measured variables: precipitation amount, precipitation chemistry, and streamflow chemistry.

INTRODUCTION

The U.S. Geological Survey, in cooperation with the U.S. Department of Energy, is conducting hydrologic and geologic investigations aimed at providing information to help evaluate the suitability of Yucca Mountain as a site for development of a high-level, nuclear-waste repository. The study activities are conducted under the Yucca Mountain Project, and the results described herein relate to the analog recharge study, one of four activities of the characterization of the Yucca Mountain Quaternary Regional Hydrology project. The objective of the 1-~~day~~ year recharge study is to describe hydrologic conditions in the Yucca Mountain area for the Quaternary, and more specifically, for the past 20,000 years. Knowledge of the paleohydrologic ground-water regime of the Yucca Mountain area is pertinent to the assessment and evaluation of the suitability of the site for development as a high-level, nuclear-waste repository. This is because information on past hydrologic conditions at Yucca Mountain and environs is essential to the development of meaningful scenarios of future hydrologic system response to climatic changes.

The analog recharge study activity was designed to evaluate the precipitation-runoff relation; and, in particular, to quantify hydrologic water-balance components that support the determination of the magnitude of ground-water recharge rates that may have existed in the past and may possibly exist in the future. The purpose of this report is to describe the results of hydrologic modeling studies conducted using data collected at two small basins in central Nevada (fig. 1). The two analog sites are located to the north and at

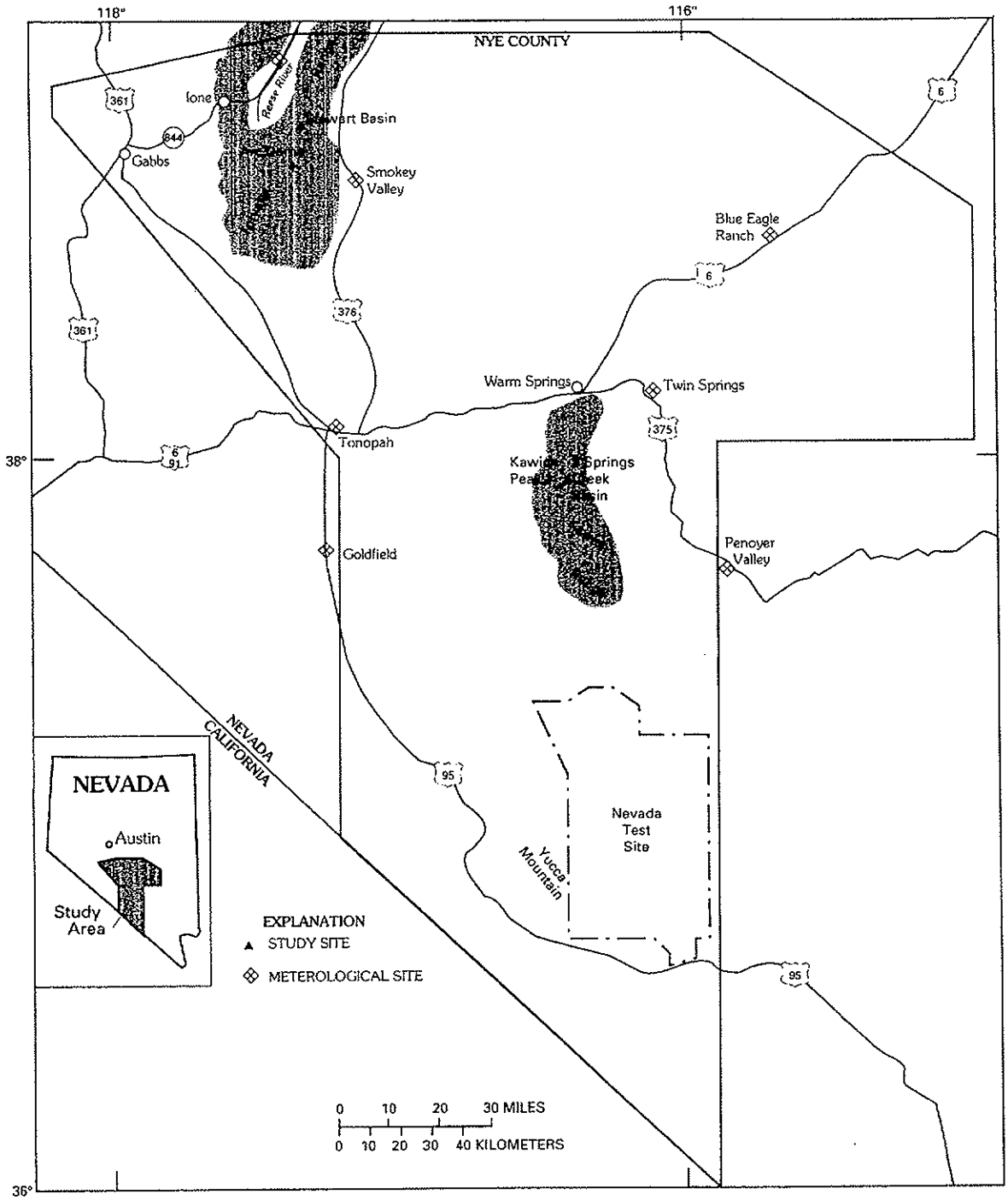

Figure 1. Locations of the study areas in Nevada.

higher elevations than the proposed Yucca Mountain repository site. The current climatic conditions at the analog site locations are thought to be representative of the possible range of paleoclimatic conditions in the general area of the repository site during the Quaternary.

Two independent, but complementary, modeling activities were conducted at each of the analog sites. Both models quantify the hydrologic water-balance equation and yield estimates of ground-water recharge, given appropriate input data.

The first modeling activity uses a traditional approach to quantify watershed hydrology by using a precipitation-runoff modeling system (PRMS) as described by Leavesley and others (1983). PRMS accounts for the spatial variability of hydrologic inputs, processes, and responses (outputs) using a daily computational time step. In some special modeling applications, a shorter computational time step may be used such as in the flood-routing simulation mode.

The second model is predicated on the conservative nature of the dissolved chloride ion in selected hydrologic environments and its use as a natural tracer is the basis for the development of a chloride-ion, mass-balance modeling algorithm (Claassen and others, 1986). The model identifies and quantifies, through operational rules of computation, the mechanisms affecting chloride-ion concentration changes from the source of the chloride ion as a constituent of precipitation input to final disposition within the watershed as discharge (including both surface and subsurface streamflow components). The model, in its original form and application, pertains to locals that typically experience a fall through winter snow-accumulation season followed by a spring snowmelt season, as is the case for the two analog basins.

DESCRIPTION OF THE STUDY AREAS

The two analog recharge study sites are in Nye County to the north and west of Yucca Mountain (fig. 1). Physical characteristics of the study basins are listed in table 1. Both study sites are characterized by high relief and rough terrain with elevations ranging from about 2,150 to 2,900 m above sea level for 3-Springs basin and from about 2,950 to 3,320 m for East Stewart basin.

The climate at 3-Springs basin is semiarid with annual precipitation generally in the range of 25 to 35 cm, most of which occurs as snow during the period October through May. Annual discharge, if any, is from snowmelt feeding subsurface flow components. Overland flow in response to storm rainfall is rare. The vegetation at 3-Springs basin can be classified into three main categories: pinon-juniper woodland, mountain mahogany woodland, and mixed upland shrub. In addition, small areas of riparian shrub exist along some of the more moist valley bottoms. The basin is drained by several small tributaries connecting to a southeast-trending main-stem branch (fig. 2). The steep side slopes of the basin are underlain by Tertiary volcanic tuffs that are exposed in numerous bedrock outcrops. Soils are fine- to coarse textured and moderately well drained except along a few moist valley bottoms. For the purpose of hydrologic modeling, the basin area was subdivided into 50 hydrologic response units, mainly on the basis of differences in slope, aspect, elevation, and canopy cover type and density.

The reason for partitioning a basin into hydrologic response units (HRU's) is to achieve an appropriately detailed specification of important "ground-truth" hydrologic characteristics. These characteristics influence not only hydrologic processes such as interception, evapotranspiration, infiltration, and so forth, but also support a meaningful representation of the spatial variability in the so-called driving data. For example, the spatial variability in temperature, precipitation, and solar radiation can be incorporated and accounted for in the delineation of HRU's. A listing of HRU characteristics is in Appendix A.

The East Stewart Creek study site is a subalpine drainage basin located to the north of Arc Dome in the Toiyabe Range north of Tonopah (fig. 1). Annual precipitation is generally in the range of 50 to 70 cm, most of which occurs as snow during the period October through May. Streamflow at East Stewart Creek is perennial and is dominated by subsurface flow components derived from infiltration of snowmelt water and its subsequent percolation and drainage through numerous springs and seeps. The thin soil mantle has little water-holding capacity and, therefore, the basin yields a high percentage of incident precipitation as runoff. Typically, 45 to 55 percent of annual precipitation over the basin is measured as runoff at the streamflow-gaging site (fig. 3). Overland flow in response to storm rainfall was not detected in the hydrograph trace.

The terrain is steep but less rugged than that exhibited at 3-Springs basin, with fewer tributaries to the main-stem branch, which flows in a northwesterly direction (fig. 3). The vegetation, which consists primarily of aspen, mountain mahogany, limber pine, and upland shrub, is much less dense than that in the 3-Springs basin area. The basin is underlain by volcanic tuffs of Tertiary age. Soils are poorly developed, shallow, highly permeable and well drained. The basin was subdivided into 15 HRU's on the basis of differences in slope, aspect, elevation, and canopy cover type and density. A listing of unit characteristics is in Appendix B.

Table 1. Characteristics of the analog study basins

[km^2, square kilometer; m, meter; deg, degree Celsius; cal cm^{-2}, calorie per square centimeter; cm, centimeter]

Name and location	Area (km^2)	Median altitude (m)	Canopy cover density in percent		Mean annual*			
			Trees	Shrubs	Temperature (deg)	Solar radiation (cal cm^{-2})	Precipitation (cm)	Runoff (cm)
3-Springs	4.20	2,500	30	8	7.8	159,600	33.64	1.07
North latitude	37.96 degrees							
West longitude	116.42 degrees							
East Stewart	0.93	3,100	19	3	3.3	143,300	63.91	33.05
North latitude	38.89 degrees							
West longitude	117.36 degrees							

*1987 through 1992 water years (October 1, 1986 - September 30, 1992).

DESCRIPTION OF MODELS

Precipitation-Runoff Modeling System (PRMS)

The precipitation-runoff modeling system (PRMS), is a deterministic, distributed-characteristic, watershed-modeling system that simulates the physical processes that comprise the land phase of the hydrologic cycle (Leavesley and others, 1983). The development and operation of PRMS is based on a conceptualization of the watershed system as an interconnected series of storage elements linked by mathematical operating rules. Figure 4 is a schematic diagram of the conceptual watershed components and the driving inputs (precipitation, air temperature, solar radiation), and outputs (streamflow, evaporation, transpiration, sublimation) that are represented for a typical HRU. The HRU concept facilitates the subdivision of a watershed into areas of similar physical characteristics and allows a reasonable approximation of the spatial variability of hydrologic response. In addition, the HRU delineation can be used to characterize differences in input driving data; for example, the influence of land slope and slope aspect on incident solar radiation.

The linkages and operations of the various components depicted in figure 4 are represented mathematically by known physical laws or empirical relations developed based on measurable watershed characteristics. Daily values of precipitation in the form of rain, snow, or a mixture of the two is the input source of moisture to the land surface. PRMS also supports storm rainfall input defined at short time intervals; for example, 5-minute data, for applications that require kinematic flood routing of surface runoff—not a significant factor for the analog study basins addressed here. The energy inputs of daily maximum and minimum air temperature and daily total solar radiation drive the processes of evaporation, transpiration, sublimation, and snowmelt.

The model structure includes four vertically stratified components that depict a surficial component represented by vegetative canopy, transient snow-covered areas, and impervious surfaces overlying three storage-reservoir components. They are: (1) a soil-zone reservoir, (2) a subsurface reservoir, and (3) a ground-water reservoir (fig. 4). The specification of an impervious-zone reservoir is used in urban environments and was not considered in the application of PRMS to the analog study basins. The operations and outputs of these components combine, on a unit area basis, to produce the simulated response of the total watershed.

Precipitation input is reduced by interception in the vegetative canopy and becomes the net precipitation at the land surface where it either accumulates as snowpack, infiltrates the soil zone, or becomes surface runoff (fig. 4). The model algorithms are structured to compute a daily water balance using values of net precipitation, adjusted maximum and minimum air tem-

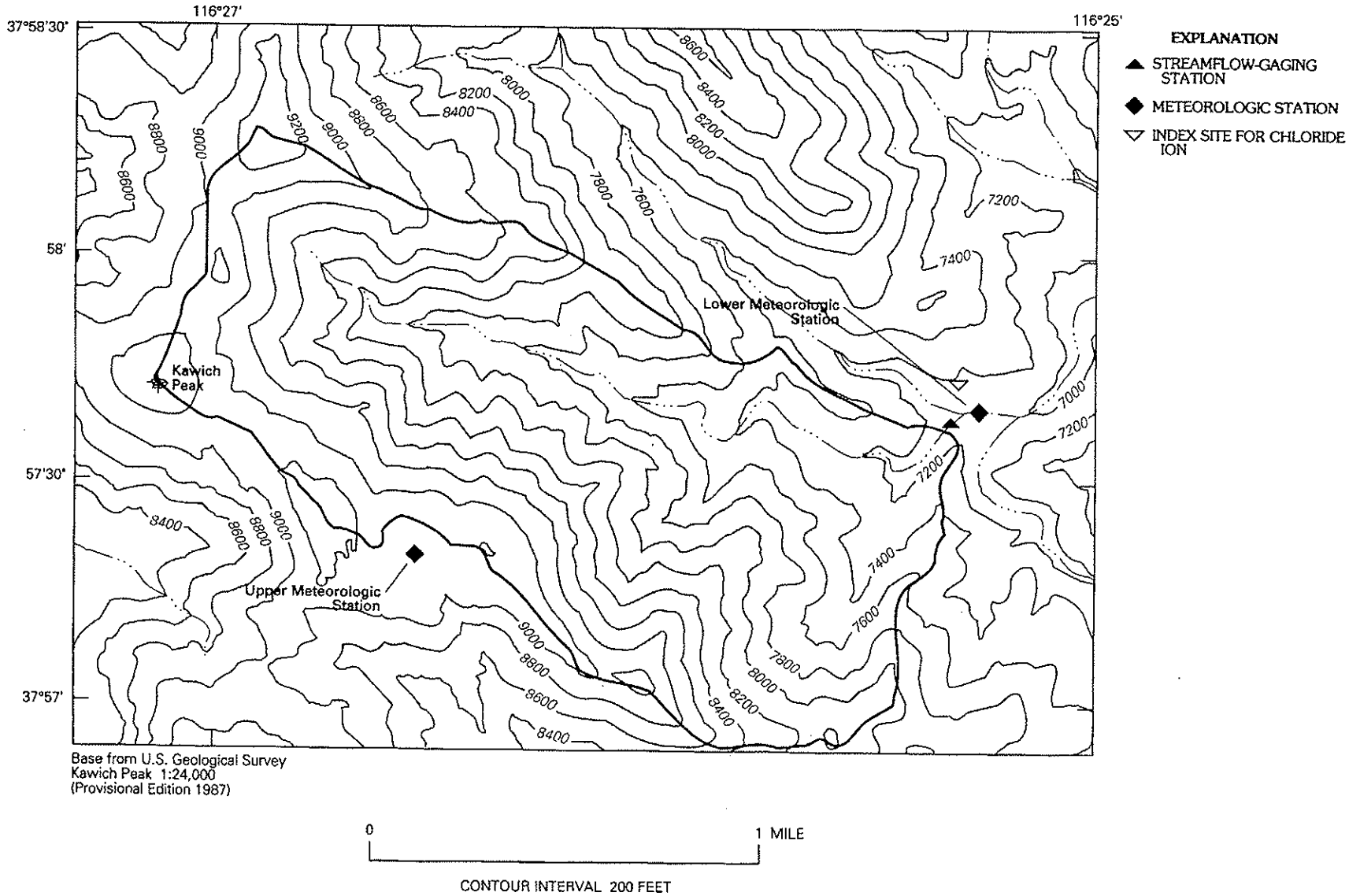

Figure 2. Topography of 3-Springs basin.

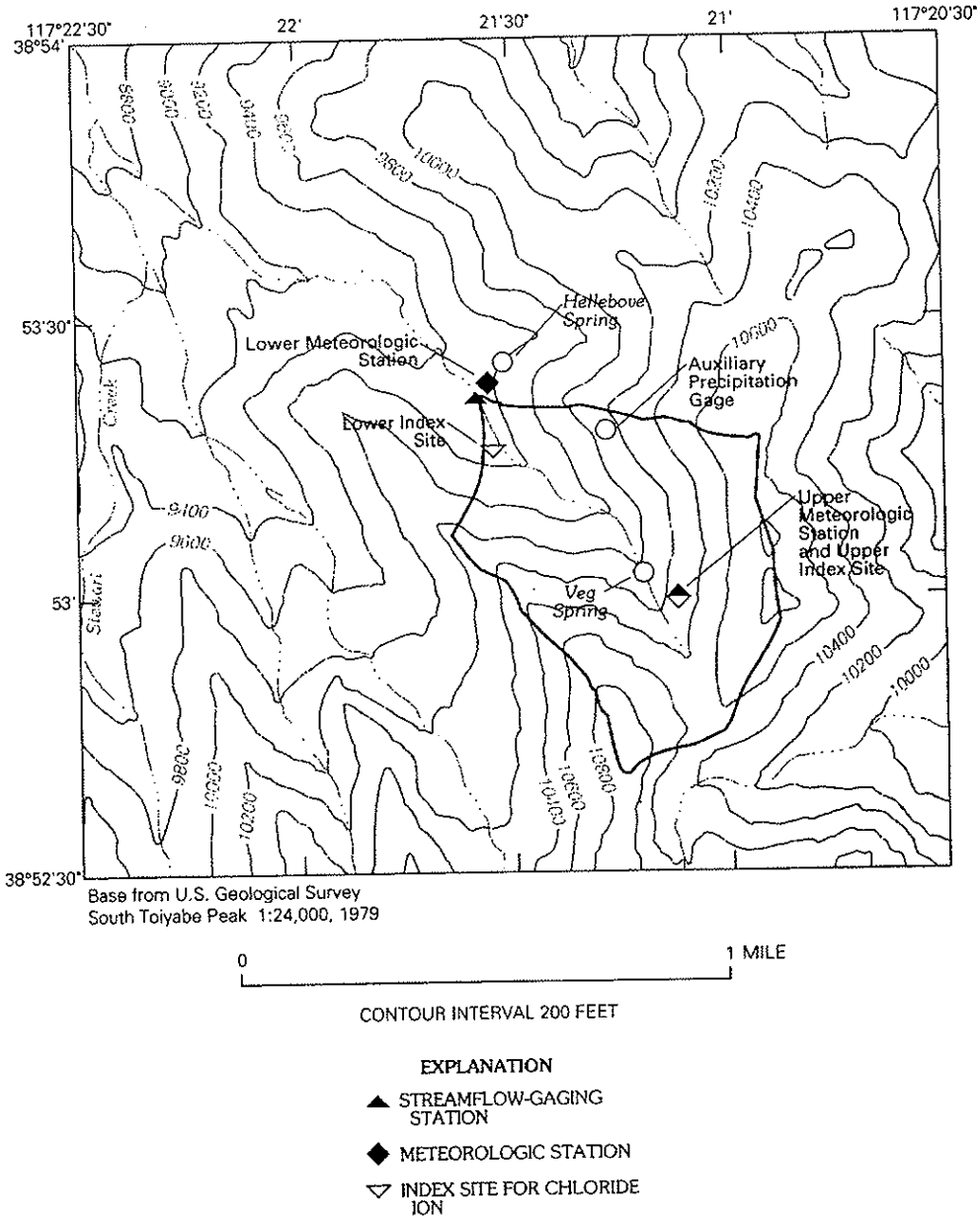

Figure 3. Topography of East Stewart Creek basin.

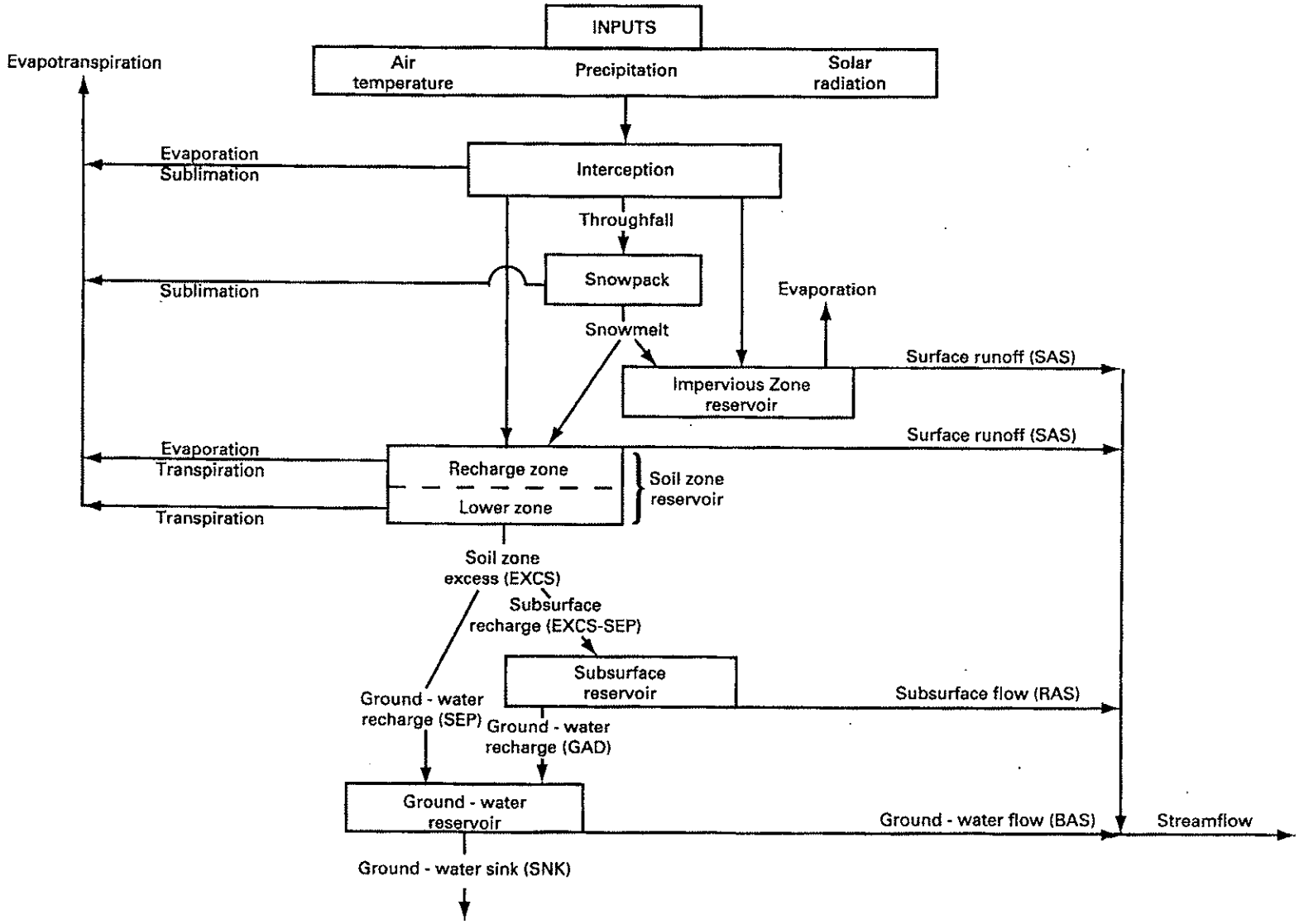

Figure 4. Schematic of the conceptual watershed system and its input (from Leavesley and others, 1983).

perature based on HRU median elevation, and solar radiation adjusted to account for HRU-specific slope and aspect.

PRMS snow components simulate the initiation, accumulation, and depletion (ablation and melt) of a snowpack on each HRU. A snowpack water-equivalent balance is computed daily, whereas the pack energy balance is updated twice daily for two 12-hour periods designated as day and night. The snowpack energy relationships were adapted from those described by Obled and Rosse (1977). The snowpack is assumed to be a two-layered system with a thin surface layer (3–5 cm) overlying the remaining snowpack. The designation of a surface layer facilitates the characterization of upper boundary conditions that are considered separately from the underlying domain as is commonly done in such problems (Obled and Rosse, 1977). Figure 5 schematically illustrates the various components of the snowpack energy-balance equations (Leavesley and others, 1983, p. 39–46).

An accounting of soil moisture for each HRU involves additions of infiltrated water, either from rainfall or snowmelt, and depletions through evaporation and/or transpiration. Soil-moisture in excess of field capacity is allocated to the subsurface and ground-water reservoirs and eventually becomes the source of fair-weather streamflow subsurface flow (RAS) and ground-water flow (BAS) (fig. 4). The soil-zone reservoir is partitioned into an upper layer (termed the recharge zone) and a lower zone. The subdivision of

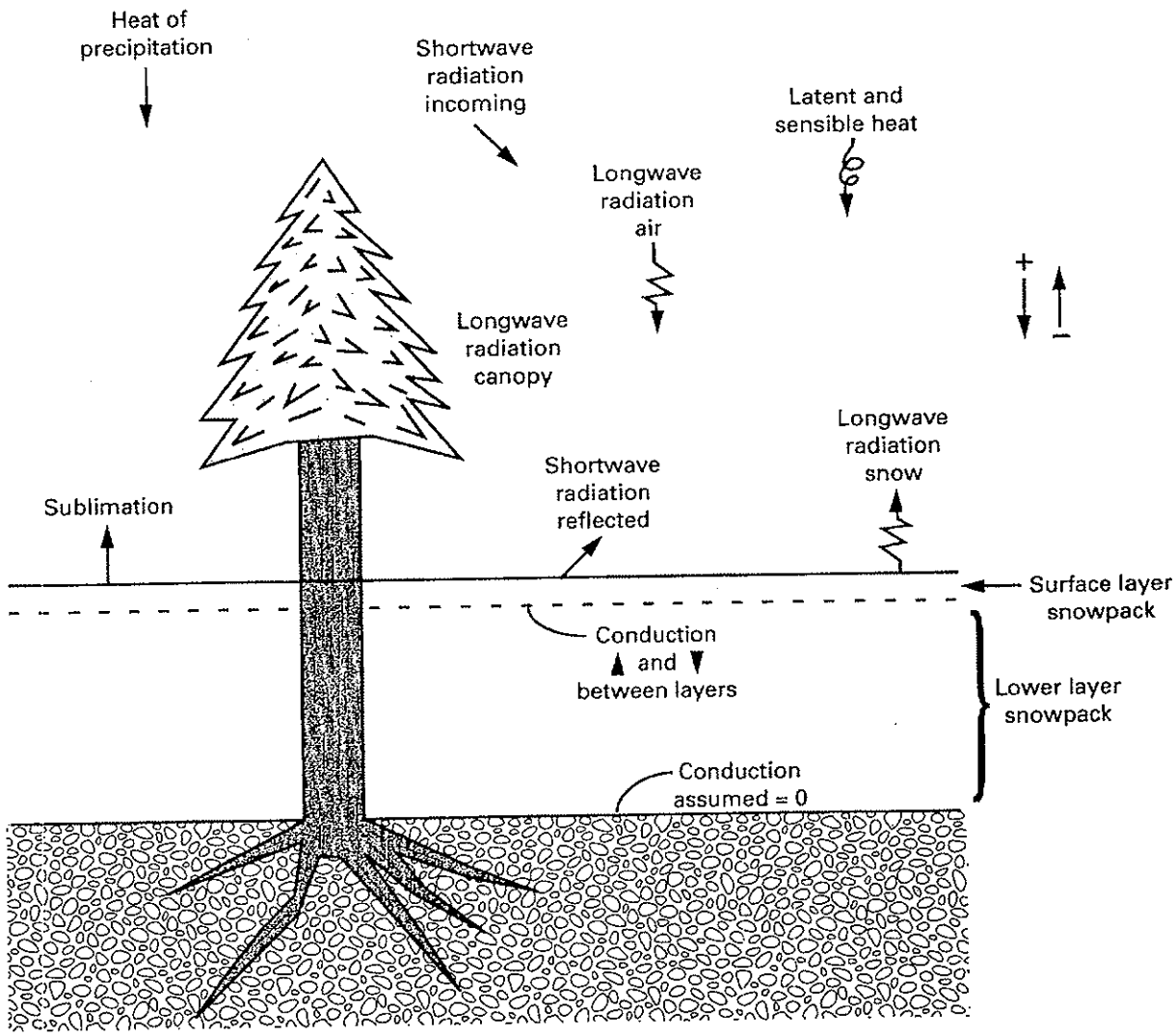

Figure 5. Components of the snowpack energy-balance equations (from Leavesley and others, 1983).

the soil zone into two partitions accommodates the computation of evaporation and transpiration losses as follows: losses from the recharge zone are assumed from evaporation and transpiration; losses from the lower zone are only through transpiration. The maximum water-holding capacity of the soil-zone reservoir (SMAX) is a key factor in water-balance computations because it largely controls the amount of soil moisture available for evapotranspiration.

Infiltration into the soil zone is dependent on the source of input. All daily snowmelt is assumed to infiltrate the soil zone until field capacity moisture level is attained. At field capacity, snowmelt infiltration is limited to a maximum daily snowmelt-infiltration capacity, SRX. Snowmelt, in excess of the capacity rate, is allocated to surface runoff, SAS (fig. 4). Infiltration amounts that are in excess of the soil-zone capacity are the source of recharge to the subsurface and ground-water reservoirs, EXCS (fig. 4). Recharge to the ground-water reservoir has first priority and is limited to a maximum daily rate, SEP. Soil-zone excess, in an amount exceeding SEP, is allocated to the subsurface reservoir. Water available for infiltration resulting from rain on snow is treated as snowmelt, if the pack is not depleted, and as rainfall otherwise. Daily infiltration of rain falling on pervious, snow-free areas is the difference between net rainfall and computed surface runoff. Surface runoff is computed using a contributing-area concept that defines the percentage of runoff as a function of current soil-moisture level and net rainfall amount (Leavesley and others, 1983, p. 27).

Daily potential evapotranspiration, PET, is computed for each HRU using the Jensen-Haise equation (Jensen and Haise, 1963) that expresses PET as a multiplicative function of daily mean-air temperature and daily solar radiation expressed as an equivalent depth of evaporation of water. Actual evapotranspiration, AET, is the computed daily water loss that reflects the availability of water to satisfy PET demand. The availability of soil water for evapotranspiration is empirically defined for three broad soil-textural classes (that is, sand, clay, and loam), as modified from Zahner (1967).

The subsurface reservoir component represents a conceptualization of shallow ground-water zones (perched ground water) that respond rapidly to recharge from soil-water excess in amounts exceeding the ground-water recharge rate (EXCS minus SEP, fig. 4). Outflow from the subsurface reservoir to a stream channel is the source of the subsurface component of streamflow (RAS, fig. 4), also known as interflow (Linsley and others, 1958). Outflow to a stream channel from the subsurface reservoir can optionally be specified as a linear or nonlinear function of storage content. In addition, another outflow path from the subsurface reservoir can be optionally directed to the ground-water reservoir (buffered ground-water recharge, GAD, fig. 4).

Recharge to the ground-water reservoir occurs from soil-water excess, EXCS, and has an upper daily limit as specified by SEP. Optionally, a second source of ground-water recharge can be represented as the buffered recharge, GAD, described above. The routing of recharge through the ground-water reservoir is the source of all baseflow (BAS, fig. 4). The ground-water reservoir is assumed to function as a linear reservoir, with rate of outflow being directly proportional to storage content. Movement of ground water to points beyond the area of study or as ground-water underflow in valley alluvium, and therefore, not measured as discharge in a stream channel, is optionally simulated as a sink term (SNK, fig. 4), that is computed as a linear function of storage in the ground-water reservoir.

Streamflow (fig. 4) is the sum of three components: surface runoff (SAS), subsurface flow (RAS), and ground-water flow (BAS). Channel routing of the various streamflow components is not performed in the daily computation mode, as was the case in the application of PRMS to the analog study basins. Channel routing of streamflow components is not a significant consideration in applying PRMS to these small watersheds because traveltimes are negligible and the dominant flow components are ground-water and subsurface flow derived from snowmelt.

A completely unique specification of values for each of the components that comprise the conceptual watershed system is rarely attempted in defining HRU characteristics for small watershed applications. For example, a single subsurface reservoir and a single ground-water reservoir is often used to represent subsurface and ground-water flows from the entire watershed. That is, all HRU's contribute recharge to common subsurface and ground-water reservoirs. However, the availability of land-surface data (that is, slope, aspect, elevation, and canopy cover density) generally supports a detailed delineation of HRU's based on these important characteristics. This is particularly true in PRMS applications to watershed hydrologies that are dominated by snow accumulation/melt processes, as is the case for the analog study basins.

Listed in table 2 are some of the more important HRU properties affecting water-balance computations, in applications of PRMS to mountain watersheds, where snow is a prime consideration. The tabulation is adapted from one presented by Parker and Norris (1989). Three categories of characteristics are identified in table 2. Category 1 includes characteristics that are determined from regional climatic characteristics

Table 2. Model input properties and their definitions

[Modified from Parker and Norris, 1989]

Property	Definition
	Category 1 - Values determined mainly from regional climatic characteristics and apply to an entire watershed or region
BST	Air temperature above which precipitation is considered rain and below which precipitation is considered all snow.
CTS	Air temperature-evapotranspiration coefficient used in Jensen-Haise potential evapotranspiration equation.
CTW	Proportion of potential evapotranspiration that may be sublimated from a snow surface.
DENI	Initial density of new-fallen snow.
DENMX	Average maximum-snowpack density.
FWCAP	Free water-holding capacity of snowpack.
PAT	Maximum air temperature that, when it is exceeded, causes spring precipitation to be rain.
SETCON	Snowpack-settlement time constant.
TLX/TLN	Lapse rate for maximum/minimum daily air temperature.
TST	Temperature index to determine beginning date of transpiration.
	Category 2 - Values determined from physical characteristics (soils, vegetation, elevation, slope, and aspect) to describe hydrologic response units
COVDNW	Winter canopy cover density.
CTX	Air temperature-evapotranspiration coefficient used in Jensen-Haise potential evapotranspiration equation.
ICOV	Predominant vegetative cover type (bare, grass, shrubs, trees).
ISOIL	Soil type (clay, loam, sand).
REMX	Maximum available water-holding capacity of soil recharge zone.
SCX/SCN	Maximum/minimum area contributing to surface runoff as a proportion of HRU area.
SMAX	Maximum available water-holding capacity of soil-zone reservoir.
SNST	Snow water equivalent interception capacity of major vegetation type.
SRX	Maximum daily snowmelt infiltration capacity of soil.
TXAJ	Slope and aspect adjustment for daily maximum air temperature.
TNAJ	Slope and aspect adjustment for daily minimum air temperature.
TRNCF	Transmission coefficient for solar radiation through canopy cover.
	Category 3 - Values determined from observed hydrograph recession shapes
RCB	Ground-water reservoir routing coefficients.
RCF/RCP	Subsurface reservoir routing coefficients.
SEP	Maximum daily recharge rate to ground-water reservoir.

and apply to an entire drainage basin or region. Category 2 specifies characteristics that are distributed in nature and are the basis for subdividing a watershed into a particular HRU configuration. Category 3 identifies characteristics relating to subsurface and ground-water reservoirs that affect the magnitude, timing, and recession characteristics of simulated discharge hydrographs. The subsurface and ground-water routing characteristics are normally derived from observed streamflow data by hydrograph separation techniques.

Chloride Model

The use of the chloride ion in quantifying hydrologic water budgets is described by Claassen and others (1986). The model is based on the conservative nature of the dissolved chloride ion in many hydrologic settings where the dominant source of the ion is from atmospheric deposition of precipitation on the land surface. Because of this constraint, the method cannot be applied to systems with a lithologic source of chloride unless these sources are accurately quantified. Fortunately, many geologic environments consisting of volcanic tuffs and intrusive rocks, as well as nonmarine sediments, quartzites, and other metamorphics contain limited sources of chloride and thus are appropriate environs for application of the model. Such is the case for the analog-recharge study basins.

Basically, the chloride model algorithm is a quantitative, basinwide accounting of the disposition of the mass of chloride deposited as a dissolved constitu-

ent in the form of precipitation. Thus, the accurate measurement or estimation of basinwide precipitation is required. The methodology requires the measurement of chloride concentration and snow-water equivalent in precipitation at an index site. In addition, the index site is equipped with a buried canister into which snowmelt percolate accumulates, by gravity drainage through the soil mantle during the spring melt period. The volume of percolate and its chloride concentration are determined and used, along with the surface measurements, to develop a coupled, water and chloride, mass-balance system of equations to quantify, on a unit area basis, the amount of sublimation at the index site.

The mass-balance equation for water is

$$P = E_s + E_t + R_g + R_s \tag{1}$$

where,

P = precipitation;
E_s = sublimation;
E_t = transpiration;
R_g = recharge (percolate); and
R_s = surface runoff.

Equation 1 omits possible changes in soil-moisture storage because the water-holding capacity of the soil is assumed to be negligible. Transpiration losses during the snow accumulation/melt seasonal accounting period are small and $E_t = 0$.

The mass-balance equation for chloride is

$$Cl_p = Cl_{Rg} + Cl_{Rs} \tag{2}$$

where,

Cl_p = total chloride in precipitation;
Cl_{Rg}= total chloride in recharge; and
Cl_{Rs}= total chloride in surface runoff, with

$$Cl_p = [Cl_p]P \tag{3}$$

$$Cl_{Rg} = [Cl_{Rg}]R_g \tag{4}$$

and

$$Cl_{Rs} = [Cl_{Rs}]R_s \tag{5}$$

where the terms in brackets denote analytical concentrations. It is assumed that homogenization of the chloride ion occurs during the melting of the snowpack and that the concentrations of the ion are identical in the meltwater source of recharge and surface runoff. Therefore,

$$[Cl_{Rg}] = [Cl_{Rs}] \tag{6}$$

With the above assumptions the mass-balance equations reduce to

$$P = E_s + R_g + R_s \tag{7}$$

and

$$[Cl_p]P = [Cl_{Rg}]R_g + [Cl_{Rg}]R_s \tag{8}$$

In this system of equations, all variables except E_s and R_s are quantified by direct measurement at the index site. Combining equations (7) and (8) and solving for E_s results in

$$E_s = P\{1 - [Cl_p]/[Cl_{Rg}]\} \tag{9}$$

Thus, E_s is computed as a function of measured quantities and R_s is computed by use of equation 7. E_s at the index site is then used in an extrapolation procedure to compute a basinwide estimate of sublimation and available water. Available water is defined as the difference between net precipitation input and sublimation loss. Thus, available water is the amount of potential runoff as quantified by the sum of R_g and R_s, equation 7.

The extrapolation procedure uses a detailed specification of the physical factors that account for the spatial differences in net precipitation and snowpack sublimation over the watershed in relation to the specific conditions at the index site. Three primary factors affect the extrapolation of the computed amount of sublimation at the index site to accomplish a basinwide accounting of the elements of the hydrologic water balance (equation 7). These are (1) spatial variability of gross precipitation; (2) spatial variability of canopy cover density and associated interception losses; and (3) spatial variability of sublimation of snow on the ground due to differences in incident solar radiation as influenced by slope, aspect, and shading (a function of canopy cover density).

The spatial variability of precipitation over mountainous watersheds is often related to elevation. At-site observations of precipitation and, in some instances, supplemental snow-course data are used to define empirical relations for specific locals, as will be described in subsequent model applications to the analog study sites. The spatial variability of canopy cover density is typically defined by timber surveys, vegetational transect data, aerial photographs, and reconnaissance mapping. These types of field and office techniques were used to assess canopy cover density patterns for the two study basins. In addition, topographic quadrangle maps (40-ft contours) were used to quantify the slope and aspect of the individual HRU's (Appendices A, B).

The effect of canopy cover density on interception is often defined by measurements of precipitation beneath various types and densities of tree canopy. These types of data are not available for the analog study basins. Therefore, an empirical relation between canopy cover density and interception developed by Claassen and others (1986) was assumed in computations for the analog basins. Claassen made measurements of interception loss under 100 percent Englemann spruce canopy density, and under no tree canopy (no interception loss). A linear relation between the two extremes was assumed (fig. 6) and corroborated by measurements made under lodgepole pine (Wilm and Dunford, 1948; U.S. Army, 1956).

The spatial variability of solar radiation over a watershed, due to differences in exposure (degree of slope and slope aspect), were determined by use of a well-documented algorithm for computing potential solar radiation on mountain slopes (Swift, 1976). The algorithm allows the computation of potential solar radiation on a daily basis. The cumulative daily potential solar radiation for each HRU and also for the index site can be computed for the seasonal accounting period (about October 1 through June 1). These cumulative totals are used to compute a solar radiation adjustment factor, S_i, for each of the HRU's. The factor is defined as the ratio of potential solar radiation at the i-th HRU to the potential radiation at the index site. The S_i factors allow for transposition of the index site estimate of seasonal snowpack water loss by sublimation, E_s, to each of the HRU's.

Another important aspect of tree canopy density on forest hydrology is the shading of the snowpack from incident solar radiation. The effect of canopy cover on the amount of solar radiation reaching the snowpack is complex, as pointed out by Satterlund and Adams (1992, p. 182). Claassen and others (1986), presented a relationship between potential sublimation of snow on the ground (as a percent) and basal area (dimensionless ratio of tree cross-sectional area to land-surface area). The relation was developed from

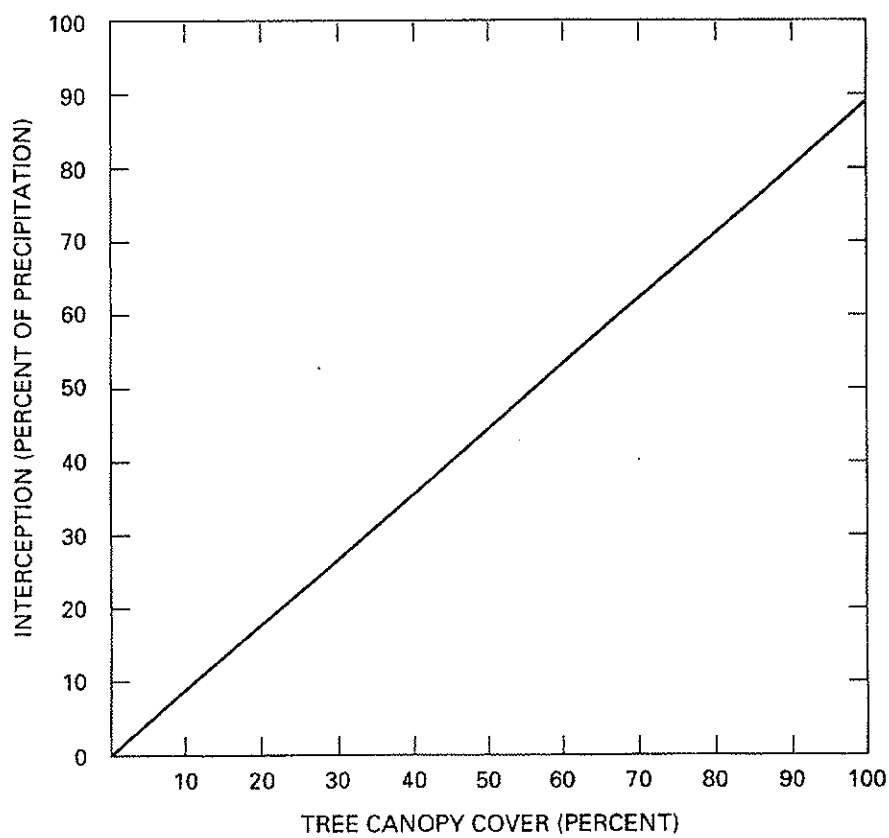

Figure 6. Effect of tree-canopy density on snow interception (modified from Claassen and others, 1986).

curves presented in Satterlund (1972, p. 169) and measurements of basal area and tree-canopy density from at-site data for their study area (Deep Creek basin in southwestern Colorado).

Because of the lack of required basal-area measurements at the study basins, another approach was used to account for the shading effects on snowpack sublimation caused by tree-canopy cover density. This approach is the so-called transmission coefficient method and is based on either measured or assumed functional relations describing the filter effect of forest canopy cover density on incident solar radiation at the snowpack. Examples of such relationships are shown in figure 7, taken from the snow accumulation/melt algorithms described by Leavesley and others (1983). The assumed relation, shown in figure 7, was used in the procedure to extrapolate index-site estimates of sublimation, E_s, for basinwide computations at the study sites.

Thus, the algorithm for calculation of available moisture, N_i, for each HRU is expressed as follows:

$$N_i = P_i - I_i - (S_i)(PS_i)(E_s') \qquad (10)$$

where,

P_i = gross precipitation;
I_i = interception loss;
S_i = solar radiation factor;
PS_i = potential sublimation as influenced by shading (fig. 7); and
E_s' = the computed sublimation at the index site corrected for shading at that site.

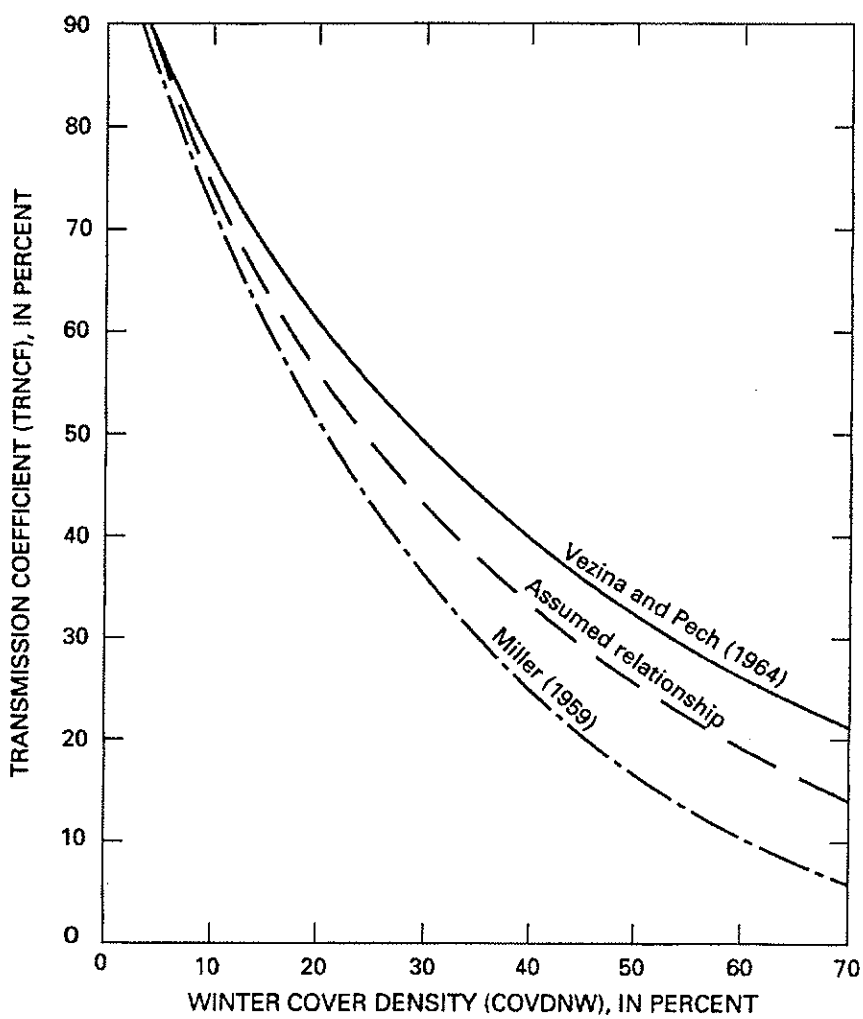

Figure 7. Functional relations between winter forest-cover density (COVDNW) and the transmission coefficient (TRNCF) of the forest canopy (from Leavesley and others, 1983).

That is, E_s' represents the index-site sublimation corrected to an open-area exposure. If the index site is located in an open area, then $E_s' = E_s$ and no correction is required as was the case for the study basins.

Available moisture for the basin is the area-weighted sum of N_i over the total of all HRU's. The basinwide estimate of available moisture can be partitioned into a ground-water recharge component and a surface-runoff component in the same proportion as indicated by the index-site computations.

The above discussion of the chloride-ion method of determining hydrologic water budgets is an abridged version of the detailed, in-depth description presented by Claassen and others (1986). In particular, the authors give extensive information on required sampling devices, sample collection and preservation techniques, and experimental design.

APPLICATION OF PRMS TO ANALOG STUDY BASINS

In contrast to the chloride-ion modeling approach, PRMS must be calibrated to best reproduce observed discharge data. It was earlier stated that the chloride-ion model yields estimates of hydrologic water-balance elements based on an extrapolation of results of computations made using data collected at an index site. The index site results are, therefore, the "calibration" of the chloride model. The calibration of PRMS using site-specific data is an iterative process that entails either (1) manual adjustment of selected characteristics to achieve specific simulated responses, and/or (2) automated parameter adjustments (optimization), so as to minimize the difference between simulated and observed daily-mean discharge.

The application of PRMS to the study basins used both manual and automated adjustment of characteristics in the fitting process. Manual adjustment of characteristics was the choice in the initial phases, so as to gain a feel for model response characteristics in these two diverse hydrologic settings. In addition, these initial efforts used a simplified configuration of HRU's, because the focus of attention was on general levels of water-balance components, and their sensitivity to characteristics quantifying (1) maximum available water-holding capacity of the soil zone, SMAX, and (2) potential evapotranspiration demand, CTS. These two characteristics largely characterize the "supply" and "demand" functions that strongly impact the annual water balance for 3-Springs and East Stewart basins.

Another important task of the initial fitting for East Stewart basin was the accurate simulation of the magnitude and timing of snowmelt as influenced by (1) correction factor for gage-catch deficiency for snowfall, DSCOR, and (2) the areal extent of snow cover as characterized by a snow cover areal depletion curve. A snow cover areal depletion curve depicts the relation between the areal extent of snow cover (percent) and a ratio defined as the current snowpack water equivalent divided by a threshold value of water equivalent associated with 100 percent areal snow cover (Anderson, 1973). The snow cover areal depletion curve is used to determine the percent of the area that is covered by snow, and thus, the portion of the area over which energy exchange is taking place during the melt phase of snowpack modeling.

3-Springs Basin

The data available for analysis at 3-Springs basin consists of daily mean discharge, daily precipitation, maximum and minimum daily temperature, and daily solar radiation for water years 1987 through 1992 (McKinley and Oliver, 1994, 1995). The water year (WY) is the 12-month period October 1 through September 30 and is designated by the calendar year in which it ends. Because of the semiarid nature of the prevailing climate and hydrologic characteristics at 3-Springs basin, mean annual runoff for the 6-year study period averaged only about 3 percent of basinwide precipitation (average annual runoff = 1.07 cm, average annual basinwide precipitation = 33.63 cm). Maximum annual runoff of 4.62 cm occurred in WY 1988 and was associated with the maximum annual basinwide precipitation value of 43.48 cm.

Basinwide precipitation values represent an adjustment to observed data values to account for the empirical relationship between land-surface altitude and yearly snow-season totals (September through May) as determined from a lower (3-Springs basin) and upper (Kawich Peak) precipitation-gaging site. The altitude of the base gage is 2,155 m and that at the upper gage is 2,755 m. The basinwide, snow-season precipitation total reflects an increase of 18 percent over the amount recorded at the lower gage (basinwide average snow correction factor of 1.18). Annual precipitation amounts reflect an increase of about 12 percent over that recorded at the lower gage.

Because of the sparseness of control data (mean daily discharge), little could be gained by undertaking an elaborate parameter-fitting scheme involving iterative optimization runs, coupled with sensitivity analysis. Therefore, a simple approach to parameter adjustments was undertaken in order to confirm the applicability of PRMS to hydrologic settings typified

by 3-Springs basin. As mentioned previously, potential evapotranspiration demand is an important factor influencing water-balance computations. The parameter CTS of the Jensen-Haise equation largely controls the magnitude of PET estimates because it functions as a multiplicative scaling parameter in the equation formulation. An estimate of the value of CTS (0.013) for 3-Springs basin was computed using appropriately quantified values of the elevation correction factor (a function of median elevation of the watershed), and the humidity index (a function of saturation vapor pressures for the mean maximum and mean minimum air temperatures for warmest month of the year) as described in Leavesley and others (1983).

Listed in table 3 are annual values and period averages of simulated potential evapotranspiration demand for three levels of the parameter CTS. Level 1 is a 10 percent reduction in the basin evaluation of CTS = 0.013, that is, CTS = 0.0117. Level 3 is a 10 percent increase in the basin value, or CTS = 0.0143. Level 2 is the estimated basin value of, CTS = 0.013. The period average value of 115.3 cm, for CTS = 0.013, closely approximates an independent estimate of 114 cm, as indicated on "Map 3, Annual free water surface evaporation" (U.S. Department of Commerce, 1982). Similarly, the average seasonal (May-October) value of 93.2 cm compares closely with the value of 89 cm as indicated on "Map 2, May-October free water surface evaporation" (U.S. Department of Commerce, 1982).

Table 3. Sensitivity of simulated annual potential evapotranspiration demand to CTS for 3-Springs basin

[cm, centimeter; CTS, air temperature-evapotranspiration coefficient used in Jensen-Haise potential evapotranspiration equation]

Water year	Potential evapotranspiration demand (cm) for given values of CTS		
	CTS = 0.0117	CTS = 0.0130	CTS = 0.0143
1987	97.87	108.74	119.61
1988	107.34	119.25	131.79
1989	112.34	124.82	137.31
1990	106.12	117.91	129.69
1991	95.22	105.82	116.41
1992	103.81	115.34	126.87
Period average	103.73	115.27	127.80
Average seasonal May-October	83.90	93.22	102.54

Observed annual runoff and precipitation data are listed in table 4, along with PRMS simulation results for each of five values of the parameter quantifying the maximum available water-holding capacity of the soil zone, SMAX. A comparison of observed and simulated results indicates that a value of SMAX of about 15 cm would be close to an optimal value. For example, SMAX = 15.24 results in a 6-year average annual simulated runoff value of 1.17 cm, as compared with the observed value of 1.07 cm. Also, in two instances (1988 and 1992), the results of simulation using SMAX = 15.24 indicate departures from observed data in excess of 1.8 cm. Errors of this magnitude can easily be attributed to subtle discrepancies (errors) in basinwide precipitation input and/or unmodeled, real-world phenomena such as winds that rapidly deplete a snowpack.

Additional insight into the utility of PRMS to simulate hydrologic conditions for 3-Springs basin is indicated by comparison of observed and simulated snowpack water equivalents listed in table 5. The two snow courses were established in 1989 in close proximity to the lower and upper precipitation-gaging sites. The intended purpose of these site locations was to assess the variability in snowpack conditions and their relation to gaged precipitation amounts. It should be noted that the upper snow course is located in a shallow bowl, about 100 m south of the drainage divide (fig. 2) and may experience somewhat different snow accumulation patterns than the typical slopes of the basin. The simulated basinwide values of snowpack water equivalent compare best with the data values for the lower snow course.

A summary of PRMS simulation results is listed in table 6. The column headings identify the major elements of the hydrologic water balance for each water year of simulated and observed data (1987–92). Also shown in table 6 are period averages that indicate the dominance of the subsurface components of simulated streamflow (RAS and BAS) over surface runoff. The sum of these two flow components indicates an average annual recharge to shallow and deep ground water of 1.14 cm. Observed average annual runoff for the 6-year period is 1.07 cm.

Hydrograph plots of observed and simulated daily-mean discharge for the period of study (water years 1987 through 1992) are shown in figures 8 and 9. There is reasonably good agreement between observed and simulated hydrograph timing, but that volume runoff amounts for discrete melt periods indicate wide dispersion. The errors in simulated runoff volumes are a consequence of the fact that observed and simulated runoff are a small fraction of basinwide precipitation, and errors of this magnitude are to be expected under these difficult modeling conditions.

Table 4. Sensitivity of simulated annual runoff to SMAX for 3-Springs basin

[cm, centimeter; SMAX, maximum available water-holding capacity of soil-zone reservoir in centimeters]

Water year	Basinwide precipitation (cm)	Observed runoff (cm)	Simulated runoff (cm) for given values of SMAX				
			5.08	10.16	15.24	20.32	25.40
1987	26.80	0.46	5.26	1.45	0.30	0.03	0.01
1988	43.48	4.67	14.07	6.96	2.79	1.17	0.33
1989	28.52	0.03	3.99	1.22	0.43	0.18	0.05
1990	29.95	0.00	3.12	0.48	0.13	0.08	0.05
1991	37.95	0.10	5.31	1.70	0.46	0.10	0.05
1992	35.05	1.09	10.36	6.12	2.97	1.09	0.15
Period average	33.63	1.07	7.01	3.00	1.17	0.43	0.10

Table 5. Simulated and observed snowpack water equivalents for 3-Springs basin

[cm, centimeter]

Date	Simulated basinwide water equivalent (cm)	Snowpack water equivalents	
		Lower snow course (cm)	Upper snow course (cm)
February 23, 1989	8.23	6.9	14.2
January 30, 1990	3.15	3.8	5.3
January 30, 1991	0.81	0.0	3.8
February 18, 1992	13.23	13.0	18.8
April 08, 1992	1.98	0.0	19.0

Table 6. Summary of simulation results for 3-Springs basin

[PPT, precipitation; PET, potential evapotranspiration; AET, actual evaporation, sublimation, and evapotranspiration from canopy, snowpack, and soil zone; SAS, overland flow to stream; RAS, subsurface flow to stream; BAS, ground-water flow to stream; SUM, total simulated streamflow; OBS, observed streamflow; cm, centimeter]

Water year	PPT (cm)	PET (cm)	AET (cm)	Change in storage (cm)	Components of streamflow			SUM (cm)	OBS (cm)
					SAS (cm)	RAS (cm)	BAS (cm)		
1987	26.80	108.74	27.99	-1.50	0.03	0.20	0.08	0.31	0.46
1988	43.48	116.71	39.27	1.42	0.13	1.91	0.76	2.80	4.67
1989	28.52	124.82	28.75	-0.69	0.02	0.03	0.41	0.46	0.03
1990	29.95	117.91	28.63	1.19	0.05	0.02	0.05	0.12	0.00
1991	37.95	105.82	36.93	0.56	0.05	0.30	0.10	0.45	0.10
1992	35.05	115.34	32.41	-0.33	0.03	2.11	0.84	2.98	1.09
Period average	33.63	115.27	32.33	0.10	0.05	0.76	0.38	1.19	1.07

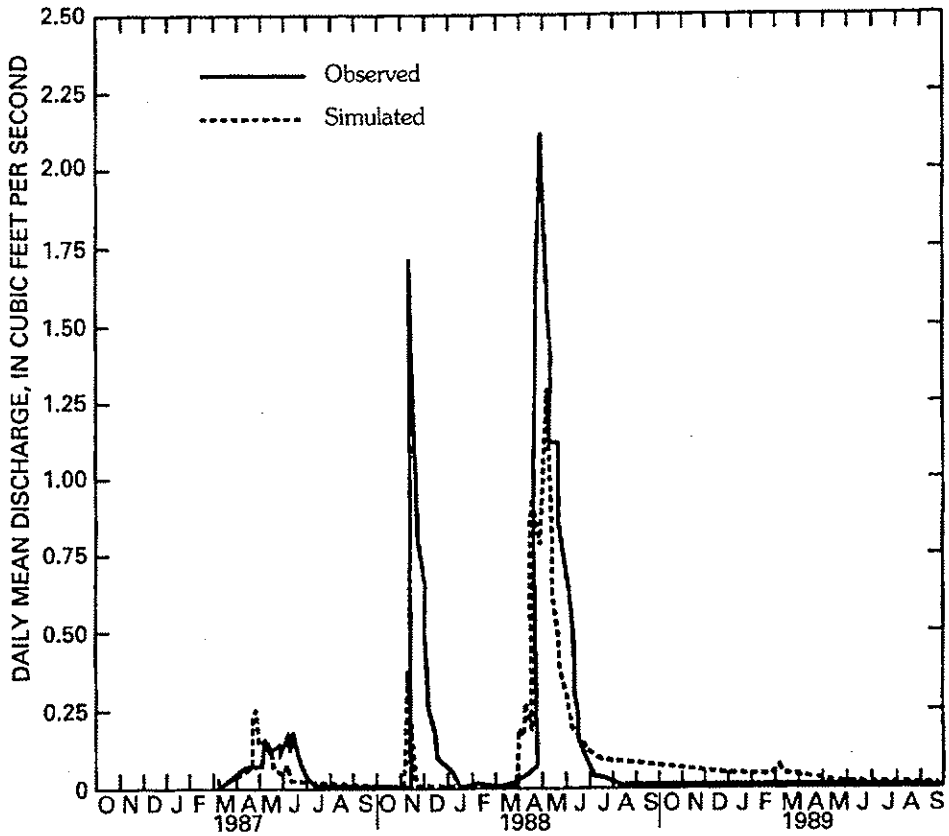

Figure 8. Observed and simulated daily-mean discharge for water years 1987 through 1989 of 3-Springs Creek, Central Nevada.

East Stewart Creek Basin

The data available for analysis at East Stewart Creek basin are considerably more extensive than that at 3-Springs basin and consists of daily mean discharge, daily precipitation at two locations (a lower- and upper-basin gaging site), maximum and minimum daily temperature, and daily solar radiation for water years 1987 through 1992 (McKinley and Oliver, 1994, 1995). It should be noted that the initial observation of streamflow was made on May 7, 1987. Total runoff for the period October 1, 1986, through May 6, 1987, was estimated to be 7.95 cm from a like period average of observed data (five periods) that exhibits low annual variability. East Stewart Creek basin is located to the north of 3-Springs basin and is situated at a higher median-basin altitude. For these reasons, East Stewart basin experiences cooler temperatures and higher precipitation amounts than 3-Springs basin. Mean-annual precipitation at East Stewart basin is almost double that at 3-Springs basin, and almost all the increase in annual precipitation is recorded as runoff in streamflow measured at the gaging station (table 1).

The fitting of PRMS to best reproduce observed discharge at the East Stewart Creek stream-gaging site involved an iterative sequence of trial adjustments to three characteristics that grossly affect simulated results. Two of the characteristics affect the magnitude of simulated annual runoff (SMAX, maximum available water-holding capacity of the soil zone, and DSCOR, daily precipitation adjustment factor for snowfall). The third parameter (SEP, maximum daily recharge rate to ground-water reservoir) controls the partitioning of simulated runoff derived from the subsurface and ground-water reservoirs (fig. 4). Analysis of observed hydrograph recessions, following the guidelines outlined in Leavesley and others (1983, p. 32–34), provided the required subsurface and

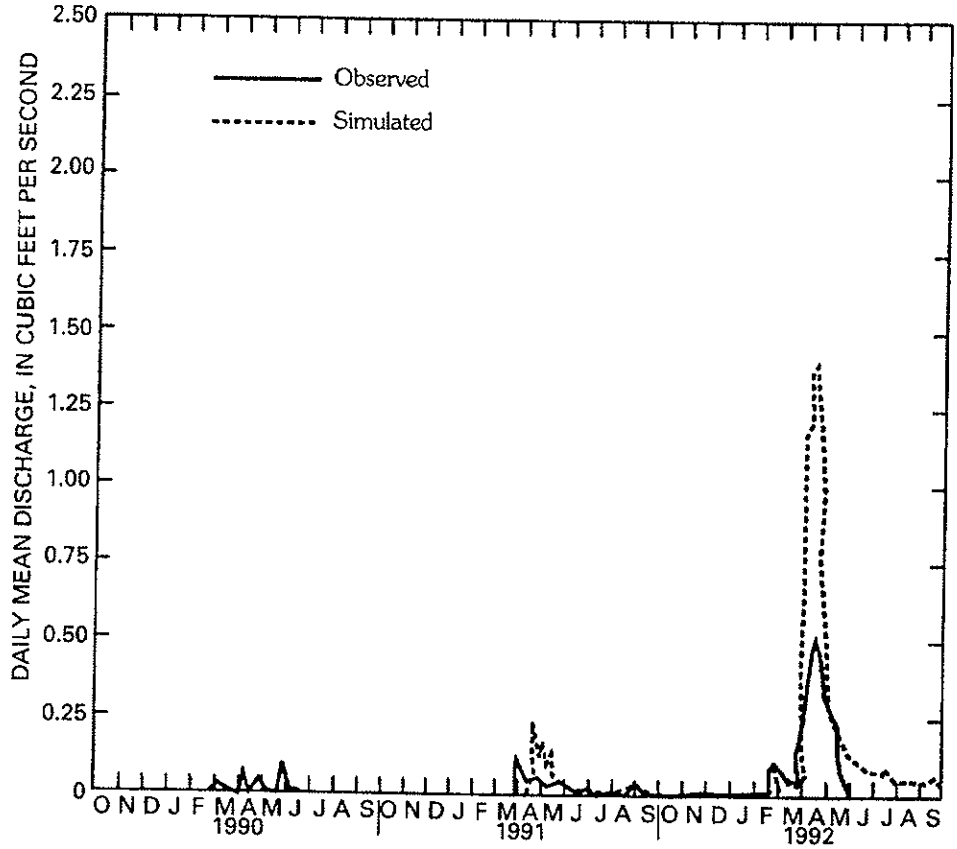

Figure 9. Observed and simulated daily-mean discharge for water years 1990 through 1992 of 3-Springs Creek, Central Nevada.

ground-water reservoir routing coefficients, RCF and RCB.

A comparison of observed data and initial simulation results indicated that modeled snowpack water equivalents were generally too low and that a winter season daily snowfall correction factor of about 1.3 (30-percent increase) would be required to approximate both the observed snowpack water equivalents as well as observed annual runoff. There is no discernible elevational relationship between winter season precipitation amounts as recorded at the lower- and upper-basin gaging sites. Therefore, the daily snow correction factor was assumed to apply to the winter season records at both the lower- and upper-gaging sites. In addition, these initial runs revealed that modeled snowmelt occurred too early and needed to be retarded in time in order to better match observed discharge. A snow cover areal depletion curve (curve B, fig. 10) adapted from Anderson (1973) was used to rectify the timing deficiencies.

Basinwide annual precipitation and observed runoff data are listed in table 7, along with PRMS simulation results for each of three values of the parameter SMAX (1.27, 2.54, and 3.81 cm). An optimal value of SMAX of between 1.27 and 2.54 cm is indicated. Recall that SMAX equals 15 cm was the appropriate value for 3-Springs basin. Values of SMAX as low as 1.27 to 2.54 cm are rare and indicative of a shallow, coarse, and highly permeable soil zone. The results presented in table 7 are conditioned on the use of the aforementioned value of DSCOR = 1.3, and also the snow cover areal depletion curve (curve B, fig. 10).

Table 8 shows a comparison of simulated, basinwide, snowpack water equivalents and those observed at the lower- and upper-basin snow courses (these results are conditioned on the use of SMAX = 2.54 cm, DSCOR = 1.3, and the areal depletion curve). Note that the simulated results are often within the range of values of the observed data. This is a self-fulfilling outcome that was achieved by the trial adjustments resulting in the fitted value of DSCOR = 1.3.

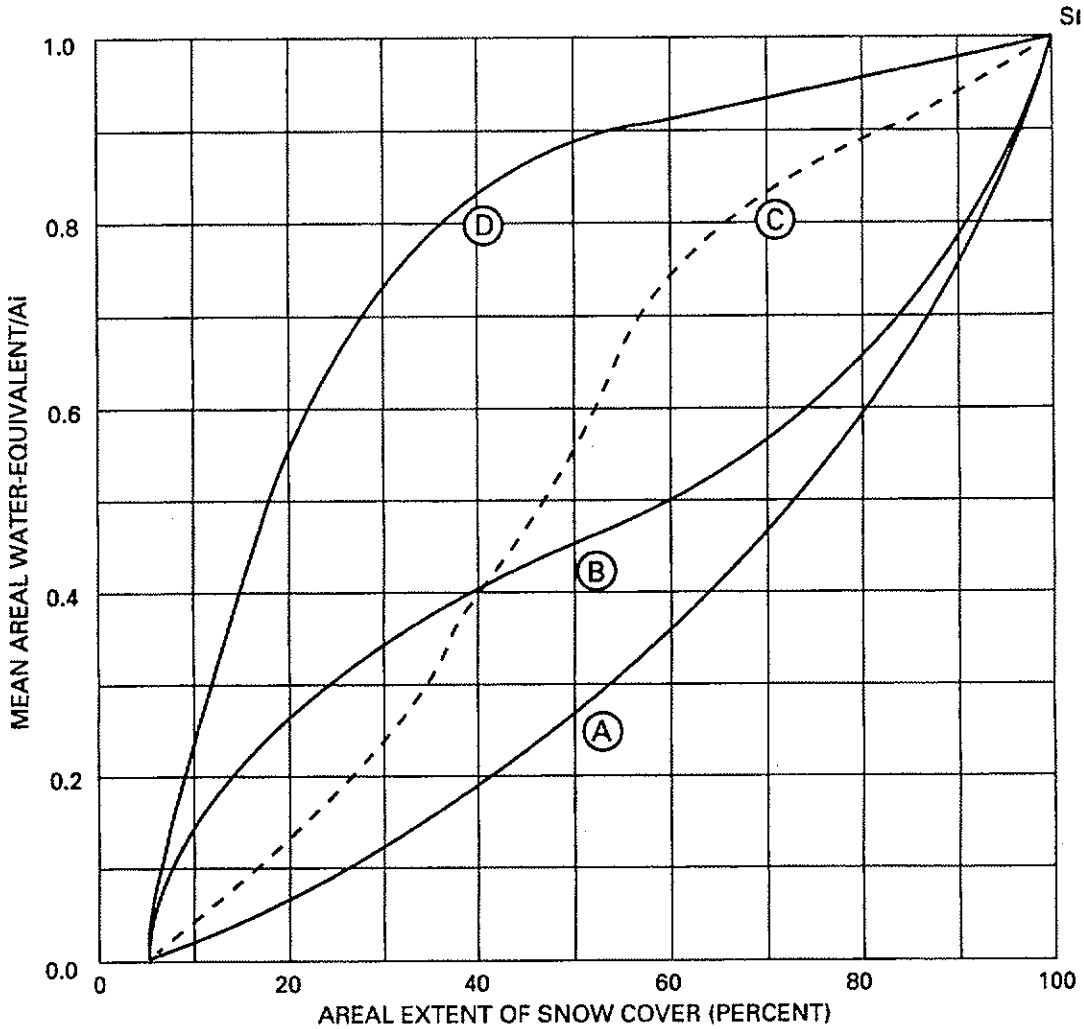

Figure 10. Characteristic shapes of snow cover areal depletion curves.

Table 7. Sensitivity of simulated annual runoff to SMAX, East Stewart Creek basin

[SMAX, maximum available water-holding capacity of the soil-zone reservoir in centimeters; cm, centimeter]

Water year	Basin-wide precipitation (cm)	Observed runoff (cm)	Simulated runoff (cm) for given values of SMAX		
			1.27	2.54	3.81
1987	55.63	35.81*	36.65	35.59	34.70
1988	88.77	39.60	48.72	46.77	45.36
1989	58.22	29.18	32.26	29.37	28.14
1990	60.05	25.98	27.79	24.69	23.19
1991	62.36	35.56	32.11	29.72	28.14
1992	58.45	32.08	30.10	27.23	25.63
Period average	63.91	33.05	34.62	32.23	30.86

*Includes estimated runoff of 7.95 cm for the period October 1 through May 6.

Table 8. Simulated and observed snowpack water equivalents, East Stewart Creek basin

[cm, centimeter]

Date	Simulated basin-wide snowpack water equivalent (cm)	Snowpack water equivalents	
		Lower snow course (cm)	Upper snow course (cm)
April 05, 1988	37.41	23.1	42.2
February 22, 1989	27.58	23.4	27.7
January 31, 1990	9.60	5.8	8.4
April 03, 1990	16.31	15.7	18.8
January 29, 1991	5.56	7.9	5.1
February 19, 1992	27.23	30.7	40.9
April 09, 1992	31.45	25.7	38.1

Comparing information listed in table 7, for water year 1988, and in table 8, for the April 5, 1988, water equivalents, the DSCOR value of 1.3 may be inappropriate for 1987–88 snow season, and most likely it is too high. That is, the high amount of basin-wide precipitation (88.77 cm) appears to be excessive in relation to the observed annual runoff of 39.60 cm. Also, note the large discrepancy between observed and simulated runoff values for 1988, on the order of 10 percent of basinwide precipitation. A value of DSCOR of about 1.2 would yield more realistic simulation results for this particular water year. A modification of this type was not considered appropriate because of the lack of onsite data on the spatial variability of precipitation, and other factors affecting snow accumulation and redistribution such as wind and drifting patterns.

The parameter SEP (table 2) controls the year-to-year amounts of baseflow contribution to simulated total annual streamflow, given that the characteristics SMAX and DSCOR are fit to approximately balance the average annual water budget. A fitted value of SEP equal to 0.64 cm/d was determined by trial and error adjustments made so as to match low-flow streamflow traces for the fall-winter periods of observed discharge data. Figures 11 and 12 illustrate the generally close correspondence between observed and simulated baseflow during recession periods (September through March).

A summary of PRMS simulation results is shown in table 9. The average potential evapotranspiration, PET, shows a much-reduced value in relation to the results presented for 3-Springs basin (table 6). Annual PET for 3-Springs basin averaged about 114 cm as compared to about 66 cm for East Stewart basin. The reduced magnitude of PET at East Stewart basin is directly related to differences in the temperature and solar radiation regimes as summarized in table 1. For example, the average solar radiation at

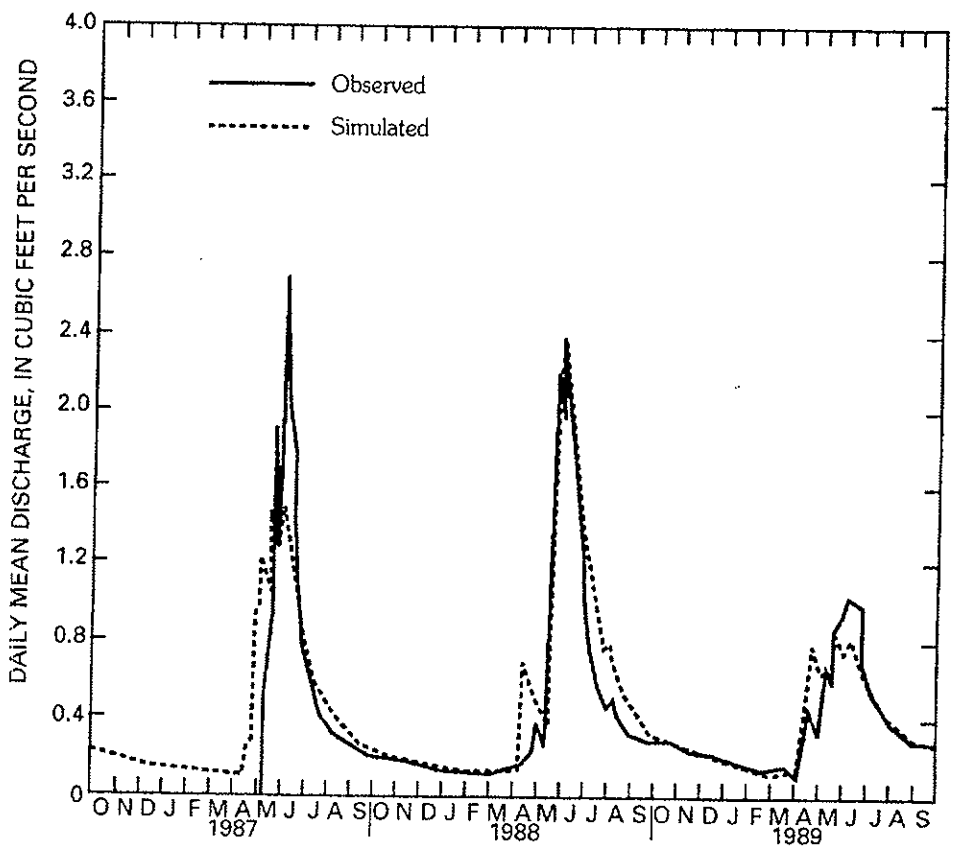

Figure 11. Observed and simulated daily-mean discharge for water years 1987 through 1989 of East Stewart Creek, Central Nevada.

East Stewart basin is about 90 percent of that recorded at 3-Springs basin, and this, coupled with lower average daily temperatures, results in reduced PET at East Stewart basin.

Period-average values of the subsurface and ground-water reservoir components of simulated streamflow listed in table 9 are approximately equal in magnitude and dominate modeled results. Note that the year-to-year variability in the magnitude of the subsurface streamflow component greatly exceeds that of the ground-water component. For example, the subsurface component ranges from 9.01 to 29.57 cm, while the ground-water component indicates a range of from 14.05 to 18.90 cm. The sum of these two flow components indicates an average annual recharge to shallow and deep ground water of 32.15 cm. This assessment assumes that negligible change in reservoir storage amounts occurred during the period, as is supported, by the magnitude of "Change in storage" indicated in table 9 (-0.18 cm). Observed average annual runoff for the 6-year period is 33.05 cm.

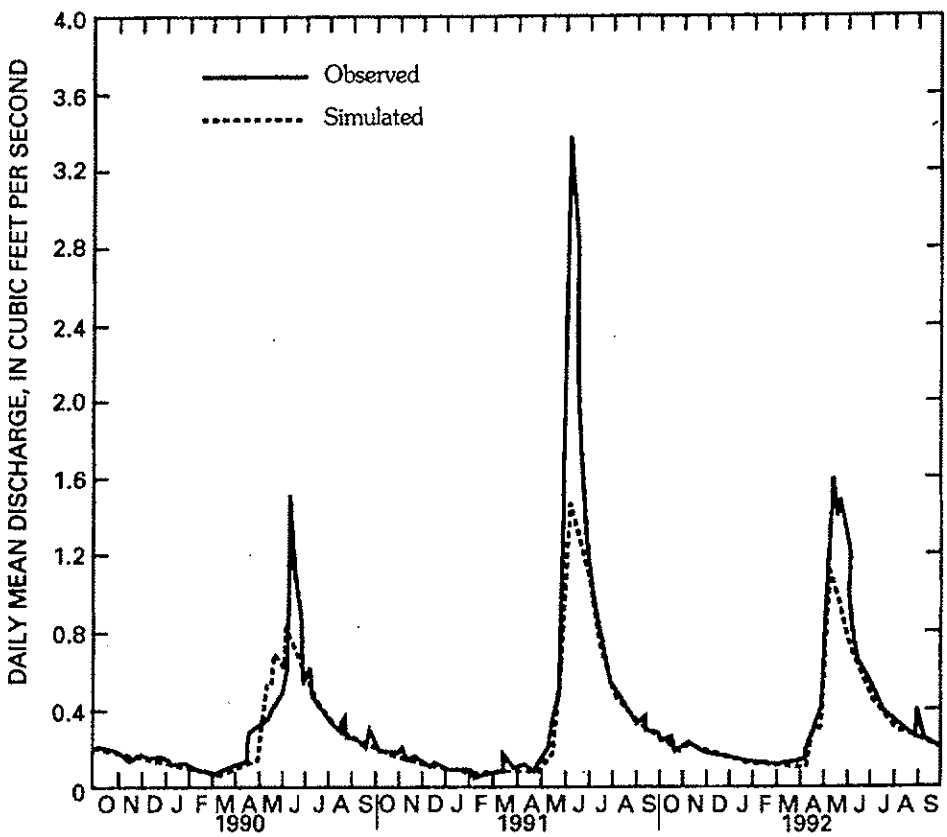

Figure 12. Observed and simulated daily-mean discharge for water years 1990 through 1992 of East Stewart Creek, Central Nevada.

Table 9. Summary of simulation results for East Stewart Creek basin

[PPT, precipitation; PET, potential evapotranspiration; AET, actual evapotranspiration from canopy, snowpack, and soil zone; SAS, overland flow to stream; RAS, subsurface flow to stream; BAS, ground-water flow to stream; SUM, total simulated streamflow; OBS, observed streamflow; cm, centimeter]

Water year	PPT (cm)	PET (cm)	AET (cm)	Change in storage (cm)	Components of streamflow			SUM (cm)	OBS (cm)
					SAS (cm)	RAS (cm)	BAS (cm)		
1987	55.63	68.12	20.65	-0.61	0.03	18.39	17.17	35.59	35.81*
1988	88.77	70.15	38.13	3.86	0.05	29.57	17.15	46.77	39.60
1989	58.22	71.98	31.80	-2.95	0.03	10.44	18.90	29.37	29.18
1990	60.05	71.50	35.71	-0.36	0.15	9.02	15.52	24.69	25.98
1991	62.36	65.02	32.26	0.38	0.05	15.62	14.05	29.72	35.56
1992	58.45	70.43	32.56	-1.37	0.08	10.36	16.79	27.23	32.08
Period average	63.91	69.55	31.85	-0.18	0.08	15.57	16.58	32.23	33.05

*Includes estimated runoff of 7.95 cm for the period October 1 through May 6.

APPLICATION OF CHLORIDE-ION MODEL TO ANALOG STUDY BASINS

The application of the chloride-ion model to the study basins used identical hydrologic response unit configurations and snow-season precipitation amounts as was used in the PRMS simulations so as to establish a credible basis for comparison of results. As mentioned previously, the extrapolation of index-site estimates of snowpack sublimation, E_s, to develop a basinwide accounting of available moisture (N_i, of equation 10), is a straight-forward computational algorithm that requires no adjustment or fitting of model characteristics. The model is "calibrated" (so to speak) by the specification of HRU characteristics.

Results of the analyses of index-site data are presented in tables 10 and 12. Table 10 lists measured data and results of computations using equations 7 and 9 for the index site at 3-Springs basin. Table 12 lists similar data and results for the two index sites at East Stewart basin (lower and upper index sites, fig. 3). The data and results listed in table 10 for 3-Springs basin indicate that the canister measurements of recharge, R_g, are inconsistent, and in 1988, exceeded the amount of snow-season precipitation. Also, in 1990, a barely measurable amount of percolate was recorded. It is obvious that the volumetric measurements of R_g recorded at the 3-Springs basin index site are nonrepresentative and of little value, as negative water balances are computed for 1987, 1988, 1991, and 1992 (table 10). However, the chloride chemistry is much better behaved and yields estimates of sublimation losses and available moisture (table 10) that are rational.

Results of extrapolation of index-site estimates of E_s to compute a basinwide accounting of available moisture using equation (10) are listed in table 11 for 3-Springs basin. The computed results listed under the column heading ($R_g + R_g'$) of table 11 are the results of interest and indicate an average annual value of available moisture of 16.61 cm for 3-Springs basin. Recall that PRMS application to 3-Springs basin required a fitted value of 15.24 cm for SMAX, the maximum available moisture storage of the soil zone. One of the assumptions of the chloride-ion model is that negligible change in soil-moisture storage occurs over a snow-season accounting period. This assumption is violated about 15 cm in the application of the method to 3-Springs basin. The algebraic difference between the basinwide estimate of average annual available moisture (16.61 cm) and the fitted value of SMAX (15.24 cm) is a fair approximation of the observed average annual runoff (1.07 cm).

The results listed in tables 12 and 13 pertain to East Stewart basin index sites and basinwide extrapolations. Again, as at 3-Springs basin, the measurements of percolate collected in the buried canisters are erratic and are of little value in assessing the relative magnitude of flow paths of available moisture (R_g and R_s). However, the results of extrapolation of index-site estimates of E_s indicate rational patterns of variability in the computed values of annual basinwide available moisture. The highest observed annual runoff is associated with the highest annual evaluations of available moisture (1988, table 13). Similarly, the lowest observed annual runoff is associated with lowest annual values of available moisture (1990, table 13).

Table 10. Water budget at index site, 3-Springs basin

[P, seasonal precipitation at index site (October 1-May 31, about); R_g, measured percolate at index site (October 1-May 31, about); $[Cl_{Rg}]$, chloride-ion concentration in percolate; $[Cl_p]$, chloride ion concentration in precipitation; E_s, evaporation/sublimation from snowpack at index site, equation 9; $(R_g + R_s)$, available moisture at index site, equation 7; cm, centimeter; $\mu mol/cm^{-3}$, micromole per cubic centimeter]

Water year	Measured variables at index site				Computed results, equations 7, 9		
	P (cm)	R_g (cm)	$[Cl_{Rg}]$ $\mu mol/cm^{-3}$	$[Cl_p]$ $\mu mol/cm^{-3}$	E_s (cm)	R_s (cm)	$(R_g + R_s)$ (cm)
1987	22.56	15.44	0.0874	0.01080	19.76	-12.64	2.80
1988	35.33	45.82	0.0344	0.00846	26.64	-37.13	8.69
1989	18.69	0.71	0.0725	0.01880	13.82	4.16	4.87
1990	20.32	0.08	0.1440	0.01180	18.67	1.57	1.63
1991	23.55	15.88	0.0592	0.01350	18.19	-10.51	5.37
1992	24.69	15.39	0.1100	0.00395	23.80	-14.50	0.89

Table 11. Extrapolation of index-site data to 3-Springs basin

[P, seasonal precipitation at index site (October 1-May 31, about); E_s, evaporation/sublimation from snowpack at index site; $(R_g + R_s)$, available moisture at index site; P', basin-wide seasonal precipitation (October 1-May 31, about); E', basinwide evaporation/sublimation from canopy and snowpack; $(R_g + R_s)$, basinwide available moisture; OBS, observed seasonal runoff; cm, centimeter]

Water year	Index site			Basin-wide extrapolation			OBS (cm)
	P (cm)	E_s (cm)	$(R_g + R_s)$ (cm)	P' (cm)	E_s' (cm)	$(R_g + R_s)'$ (cm)	
1987	22.56	19.76	2.80	26.67	11.46	15.21	0.46
1988	35.33	26.64	8.69	41.76	16.71	25.05	4.67
1989	18.69	13.82	4.87	22.10	8.76	13.34	0.03
1990	20.32	18.67	1.63	24.00	10.54	13.46	0.00
1991	23.55	18.19	5.37	27.84	11.25	16.59	0.10
1992	24.69	23.80	0.89	29.18	13.13	16.05	1.09
Period average	24.18	20.14	4.04	28.60	11.98	16.62	1.07

Table 12. Water budgets at lower and upper index sites, East Stewart Creek basin

[P, seasonal precipitation at index site (September 15-June 15, about); R_g, measured percolate at index site (September 15-June 15, about); $[Cl_{Rg}]$, chloride-ion concentration in percolate; $[Cl_p]$, chloride-ion concentration in precipitation at a single sampling site; E_s, evaporation/sublimation from snowpack at index site, equation 9; $(R_g + R_s)$, available moisture at index site, equation 7; cm, centimeter; $\mu mol/cm^{-3}$, micromole per cubic centimeter]

Water year	Measured at lower index site				Computed results, equations 7, 9		
	P (cm)	R_g (cm)	$[Cl_{Rg}]$ $\mu mol/cm^{-3}$	$[Cl_p]$ $\mu mol/cm^{-3}$	E_s (cm)	R_s (cm)	$(R_g + R_s)$ (cm)
1987	58.75	18.47	0.0254	0.00649	43.74	-3.46	15.01
1988	64.80	2.03	0.0592	0.01330	50.24	12.53	14.56
1989	50.90	0.15	0.1830	0.01380	47.07	3.68	3.83
1990	46.74	0.08	0.5080	0.01240	45.59	1.07	1.15
1991	57.73	0.10	0.0564	0.01100	46.48	11.15	11.25
1992	49.20	0.48	0.0395	0.01070	35.86	12.86	13.34
Water year	**Measured at upper index site**				**Computed results, equations 7, 9**		
	P (cm)	R_g (cm)	$[Cl_{Rg}]$ $\mu mol/cm^{-3}$	$[Cl_p]$ $\mu mol/cm^{-3}$	E_s (cm)	R_s (cm)	$(R_g + R_s)$ (cm)
1988	83.44	5.13	0.0195	0.01330	26.52	51.79	56.92
1989	53.06	0.13	0.2000	0.01380	49.40	3.53	3.66
1990	46.99	0.86	0.0790	0.01240	39.62	6.51	7.37
1991	57.18	2.16	0.0223	0.01100	28.98	26.05	28.21
1992	50.72	14.20	0.0130	0.01070	8.97	27.55	41.75

Table 13. Extrapolation of index-site data to East Stewart Creek basin

[P, seasonal precipitation at index site (September 15-June 15, about); E_s, evaporation/sublimation from snowpack at index site; $(R_g + R_s)$, available moisture at index site; P', basinwide seasonal precipitation (September 15-June 15, about); E_s', basinwide evaporation/sublimation from canopy and snowpack; $(R_g + R_s)$, basinwide available moisture; OBS, observed seasonal runoff (March 1-February 28, 29); cm, centimeter]

Water year	Lower index site			Basinwide extrapolation			
	P (cm)	E_s (cm)	$(R_g + R_s)$ (cm)	P' (cm)	E_s' (cm)	$(R_g + R_s)'$ (cm)	OBS (cm)
1987	58.75	43.74	15.01	55.60	30.99	24.61	35.00
1988	64.80	50.24	14.56	79.58	37.92	41.66	41.71
1989	50.90	47.07	3.83	52.60	32.05	20.55	28.22
1990	46.74	45.59	1.15	46.94	30.38	16.56	24.84
1991	57.73	46.48	11.25	57.30	32.59	24.71	37.52
1992	49.20	35.86	13.34	50.42	26.16	24.26	30.20
Period average	54.69	44.83	9.86	57.07	31.67	25.37	32.92
Water year	**Upper index site**			**Basinwide extrapolation**			
	P (cm)	E_s (cm)	$(R_g + R_s)$ (cm)	P' (cm)	E_s' (cm)	$(R_g + R_s)'$ (cm)	OBS (cm)
1988	83.44	26.52	56.92	79.58	25.27	54.30	41.71
1989	53.06	49.40	3.66	52.60	31.60	21.00	28.22
1990	46.99	39.62	7.37	46.94	26.16	20.78	24.84
1991	57.18	28.98	28.21	57.30	22.96	34.34	37.52
1992	50.72	8.97	41.75	50.42	12.52	37.90	30.20
Period average	58.27	30.68	27.59	57.35	23.70	33.66	32.49

The computed amounts of available moisture using the lower index-site extrapolations are consistently less than those computed using upper index-site data. Compare for example, the period-average values of 25.37 and 33.66 cm. The deviation of about 8 cm is not excessive and could easily be removed by a 10-percent reduction in the E_s values at the lower site, coupled with a 10-percent increase in E_s at the upper site. Overall, the results of extrapolation could be judged as informative and only slightly biased. The low value of maximum available soil-moisture storage (SMAX = 2.54 cm), as indicated from PRMS fitting, is the reason East Stewart basinwide computations of available moisture show a closer relation to observed runoff amounts than those for 3-Springs basin.

REDUCED FORM OF THE CHLORIDE-ION MODEL

The use of chloride-ion concentrations in precipitation inputs and those measured in water samples of streamflow offers an alternative approach to the index-site extrapolation procedure to assess basinwide, average-annual evapotranspiration and sublimation losses ($E_t + E_s$), and available moisture ($R_g + R_s$) (equation 1). This potential application of the interrelation of chloride-ion water chemistry was suggested in Claassen and others (1986). The reduced form of the chloride-ion model cannot yield estimates of the magnitudes of the individual runoff components R_g and R_s because there is no direct evaluation of either component as in the index-site extrapolation approach. In addition, it would be difficult to attempt an annual evaluation of the lumped components (that is, $E_t + E_s$, and $R_g + R_s$) and therefore, time-averaged data are used in the following analysis.

Listed in table 14 are the results of the reduced, time-average approach to estimate available moisture using average annual basinwide precipitation, and average values of chloride-ion concentration in precipitation and streamflow for water years 1987 through 1992. The concentration values listed for precipitation are the result of a volume-weighted computation that integrates the total mass of chloride over the time interval. The concentration values for streamflow are a simple average of the data available from grab samples collected at or near the streamflow-gaging sites. The computed results listed in table 14 are derived from a slight modification of equation 9 as

$$E_t + E_s = P\{1 - [Cl_p]/[Cl_{sf}]\} \qquad (11)$$

where the sum $E_t + E_s$ represents total average annual losses, P is average annual basinwide precipitation, $[Cl_p]$ is average chloride-ion concentration in precipitation, and $[Cl_{sf}]$ is average concentration of water samples of streamflow (the variability of chloride-ion concentration in streamflow samples is low, with coefficient of variation of about 15 percent).

The values of available moisture shown in table 14 (column heading $R_g + R_s$) are approximately the same magnitude as observed estimates of average annual runoff, and also the values indicated by PRMS simulation results. A compilation of the results of the PRMS and two versions of the chloride ion are shown in table 15. As mentioned previously, the excessive value of estimated recharge derived from the index-site extrapolation procedure for 3-Springs basin is due to the storage and subsequent evapotranspiration of about 15 cm of water from the soil zone.

Table 14. Average annual losses ($E_t + E_s$), and available moisture ($R_g + R_s$) for the analog study basins

[cm, centimeter; μmol/cm^{-3}, micromole per cubic centimeter]

Basin	Average annual basin-wide precipitation (cm)	Average chloride concentration		Computed results	
		In precipitation (μmol/cm^{-3})	In streamflow (μmol/cm^{-3})	($E_t + E_s$) (cm)	($R_g + R_s$) (cm)
3-Springs	33.63	0.0101	0.1040	30.35	3.28
East Stewart	63.91	0.0112	0.0231	32.92	30.99

Table 15. Compilation of observed data and model estimates of average annual recharge for study basins

[cm, centimeter; PRMS, precipitation-runoff modeling system]

Basin	Average annual values of		Model estimates of average annual recharge		
	Basin-wide precipitation (cm)	Observed runoff (cm)	PRMS (cm)	Index-site extrapolation (cm)	Reduced chloride-ion model, eq (11) (cm)
3-Springs	33.63	1.07	1.14	16.62	3.28
East Stewart	63.91	33.05	32.16	29.51*	30.99

*Value is average of lower and upper index-site extrapolations.

SUMMARY AND CONCLUSIONS

The results of the application of PRMS to model the land phase of the hydrologic cycle for two diverse, high-altitude basins in central Nevada reaffirms the general utility of the system, given that an adequate base of data is available. The required data base is extensive in comparison to that required for the application of either the index-site, chloride-ion modeling approach (extrapolation via equation 10), or the reduced chloride-ion model (time-averaged data via equation 11). However, the detail of inquiry afforded by PRMS exceeds that available from either of the chloride-ion models. For example, a complete time-series evaluation of water-balance elements is available for analysis from PRMS output. However, if such detailed analysis and evaluation of time-series information is not of primary concern, then a modeling approach requiring less extensive data would be justified. The reduced chloride-ion model satisfies this later scenario.

It is concluded that the modeling approaches yield reasonably consistent and accurate estimates of average-annual recharge to ground water in these two diverse hydrologic settings. Average-annual values of modeled recharge range from about 1 to 3 cm/yr for 3-Springs basin. Comparable results for East Stewart Creek basin range from about 30 to 32 cm/yr. The most reliable results are those derived from the reduced chloride-ion model because they reflect integrated basin-wide processes in terms of only three measured variables, precipitation amount, precipitation chemistry, and streamflow chemistry.

REFERENCES CITED

Anderson, E.A., 1973, National Weather Service river forecast system—snow accumulation and ablation model: U.S. Department of Commerce, NOAA, Technical Memorandum NWS HYDRO-17, 217 p. [Available only from the National Technical Information Service, Springfield, VA 22161, acquisition no. COM-74-10728.]

Claassen, H.C., Reddy, M.M., and Halm, D.R., 1986, Use of the chloride ion in determining hydrologic-basin water budgets—A 3-year case study in the San Juan Mountains, Colorado, U.S.A.: Journal of Hydrology, no. 85, p. 49–71.

Dickinson, W.T., and Whiteley, H.Q., 1970, Watershed areas contributing to runoff: International Association of Hydrologic Sciences Publication 96, p. 1.12–1.28.

Hewlett, J.D., and Nutter, W.L., 1970, The varying source area of streamflow from upland basins, in Symposium on Interdisciplinary Aspects of Watershed Management, Montana State University, Bozeman, Montana, 1970, Proceedings, p. 65–83.

Jensen, M.E., and Haise, H.R., 1963, Estimating evapotranspiration from solar radiation: Proceedings of the American Society of Civil Engineers, Journal of Irrigation and Drainage, v. 89, no. IR4, p. 15–41.

Leavesley, G.H., Lichty, R.W., Troutman, B.M., and Saindon, L.G., 1983, Precipitation-runoff modeling system—User's manual: U.S. Geological Survey Water-Resources Investigations Report 83-4238, 207 p.

Linsley, R.K., Jr., Kohler, M.A., and Paulhus, J.L.H., 1958, Hydrology for engineers: McGraw-Hill, New York, 340 p.

McKinley, P.W., and Oliver, Thomas, 1994, Meteorological, discharge, and water-quality data from two small basins in central Nevada: U.S. Geological Survey Open-File Report 93-651, 167 p.

McKinley, P.W., and Oliver, Thomas, 1995, Meteorological, stream-discharge, and water-quality data for water year 1992 from two small basins in central Nevada: U.S. Geological Survey Open-File Report 94-456, 56 p. (MOL.19950124.0284)

Obled, C., and Rosse, B.B., 1977, Mathematical models of a melting snowpack at an index plot: Journal of Hydrology, no. 31/32, p. 139–163.

Parker, R.S., and Norris, J.M., 1989, Simulation of streamflow in small drainage basins in the southern Yampa River Basin, Colorado: U.S. Geological Survey Water-Resources Investigations Report 88-4071, 47 p.

Satterlund, D.R., 1972, Wildland watershed management: Wiley, New York, 370 p.

Satterlund, D.R., and Adams, P.W., 1992, Wildland watershed management-second edition: Wiley, New York, 436 p.

Swift, L.W., Jr., 1976, Algorithm for solar radiation on mountain slopes: Water Resources Research, v. 12, no. 1, p. 108–112.

U.S. Army, 1956, Snow hydrology: Portland, Oreg., U.S. Army Corps of Engineers, North Pacific Division, 437 p.

U.S. Department of Commerce, 1982, Evaporation atlas for the contiguous 48 United States: National Oceanic and Atmospheric Administration Technical Report NWS 33, 26 p.

Wilm, H.G., and Dunford, E.G., 1948, Effect of timber cutting on water available for streamflow from a lodgepole pine forest: U.S. Department of Agriculture Technical Bulletin 968, 43 p.

Zahner, R., 1967, Refinement in empirical functions for realistic soil-moisture regimes under forest cover, *in* Sopper, W.E., and Lull, H.W., eds., International symposium of forest hydrology: New York, Pergamon Press, p. 261–274.

APPENDIX A.

Hydrologic response unit characteristics for 3-Springs basin

Hydrologic response unit number	Area (hectares)	Slope (percent)	Aspect (degree)	Altitude (meter)	Canopy cover density (percent)	Transmission coefficient (percent)	Snow correction factor
1	8.5	39	315	2,230	50	25	1.04
2	12.7	51	310	2,345	80	15	1.10
3	5.4	40	0	2,500	40	33	1.17
4	7.2	42	165	2,220	30	43	1.03
5	11.4	32	33	2,220	50	25	1.03
6	9.5	60	55	2,345	50	25	1.10
7	13.4	60	70	2,315	40	33	1.08
8	9.5	55	90	2,375	40	33	1.11
9	9.6	55	20	2,375	40	33	1.11
10	16.0	76	80	2,560	40	33	1.20
11	5.8	93	75	2,680	30	43	1.26
12	8.3	57	180	2,270	30	43	1.06
13	6.8	78	330	2,330	60	18	1.09
14	6.6	75	355	2,500	60	18	1.17
15	9.3	68	335	2,610	40	33	1.23
16	10.0	80	55	2,635	40	33	1.24
17	12.9	64	180	2,605	30	43	1.23
18	13.5	59	80	2,415	30	43	1.13
19	13.6	71	80	2,560	30	43	1.20
20	4.7	73	25	2,355	30	43	1.10
21	5.4	73	10	2,530	40	33	1.19
22	7.7	64	45	2,680	40	33	1.26
23	5.7	57	220	2,440	40	33	1.14
24	14.4	54	45	2,440	30	43	1.14
25	8.6	54	0	2,620	40	33	1.23
26	7.0	50	25	2,745	15	65	1.30
27	6.8	55	150	2,440	30	43	1.14
28	13.6	55	180	2,500	20	57	1.17
29	11.5	50	0	2,530	30	43	1.19
30	8.9	55	190	2,560	15	65	1.20
31	7.0	64	5	2,720	20	57	1.28
32	5.8	64	160	2,585	10	75	1.22
33	6.7	66	20	2,530	40	33	1.19
34	5.4	70	80	2,510	30	43	1.18
35	5.7	30	45	2,710	30	43	1.28

Hydrologic response unit characteristics for 3-Springs basin--Continued

Hydrologic response unit number	Area (hectares)	Slope (percent)	Aspect (degree)	Altitude (meter)	Canopy cover density (percent)	Transmission coefficient (percent)	Snow correction factor
36	3.9	70	230	2,595	10	75	1.22
37	5.1	46	100	2,560	50	25	1.20
38	8.2	45	70	2,535	15	65	1.19
39	11.0	28	40	2,705	15	65	1.28
40	9.6	30	40	2,805	40	33	1.33
41	4.7	57	185	2,620	50	25	1.23
42	5.9	64	155	2,800	0	100	1.32
43	11.5	57	165	2,670	50	25	1.26
44	10.9	60	90	2,695	40	33	1.27
45	9.4	57	130	2,715	50	25	1.28
46	9.3	56	80	2,620	50	25	1.23
47	2.5	55	90	2,775	0	100	1.31
48	3.2	34	90	2,470	95	10	1.16
49	6.4	38	45	2,345	95	10	1.10
50	3.2	13	100	2,315	95	10	1.09

Generic parameters common to all HRU's:

Maximum daily snowmelt infiltration capacity, SRX	5.08 cm/d
Maximum daily recharge to ground-water reservoir, SEP	0.25 cm/d
Subsurface reservoir routing coefficient, RCF	0.0910
Ground-water reservoir routing coefficient, RCB	0.0058

APPENDIX B.

Hydrologic response unit characteristics for East Stewart Creek basin

Hydrologic response unit number	Area (hectares)	Slope (percent)	Aspect (degree)	Altitude (meter)	Canopy cover density (percent)	Transmission coefficient (percent)	Snow correction factor
1	1.1	53	25	2,910	18	60	1.30
2	1.0	68	225	2,910	18	60	1.30
3	2.9	53	25	2,950	5	85	1.30
4	5.8	61	260	3,110	10	75	1.30
5	13.7	64	280	3,170	40	33	1.30
6	1.7	52	260	3,170	5	85	1.30
7	6.1	53	55	3,050	15	65	1.30
8	22.5	60	15	3,050	15	65	1.30
9	10.9	63	245	3,050	60	18	1.30
10	2.7	26	28	2,930	10	75	1.30
11	0.7	57	275	2,930	10	75	1.30
12	12.1	52	260	3,255	10	75	1.30
13	3.8	53	55	3,230	10	75	1.30
14	7.6	57	20	3,230	10	75	1.30
15	0.8	15	305	2,960	10	75	1.30

Generic parameters common to all HRU's:

Maximum daily snowmelt infiltration capacity, SRX	5.08 cm/d
Maximum daily recharge to ground-water reservoir, SEP	0.64 cm/d
Subsurface reservoir routing coefficient, RCF	0.0333
Ground-water reservoir routing coefficient, RCB	0.0058

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been approximately 70 percent higher, on average, than the rates listed in Table A6-6 using present-day precipitation rates and Cl^- concentrations. On the other hand, if Cl^- deposition rates in the Pleistocene were approximately the same as today, as inferred by (Plummer et al. 1997 [DIRS 107034], p. 540) from $^{36}Cl/Cl$ ratios in packrat middens, the infiltration rates listed in Table A6-8 using present-day Cl^- deposition rates are valid.

A6.3.6.6 Evaluation of Evidence for Timing of Recharge

Hydrochemical data that bear on the question of the age or timing of local recharge include hydrogen and oxygen isotope ratios and ^{14}C activities. Hydrogen and oxygen isotope ratios may contain age information because the numerical values of these ratios in groundwaters reflect the climate under which the waters were infiltrated. Therefore, if waters were recharged in a climatic regime different from the current regime, this fact should be reflected in the isotope ratios of the groundwaters.

The activity of ^{14}C in a particular groundwater sample potentially offers a more direct indication of the time at which that groundwater was recharged. In general, the older the sample, the lower the ^{14}C activity. However, the interpretation of the age of a groundwater sample from ^{14}C activity data is complicated by the fact that groundwaters can undergo soil-water-rock-gas interactions that can alter the proportions of carbon isotopes in a groundwater sample. This process, in turn, can lead to modification of the age calculated for the sample based on ^{14}C activity as discussed further below.

Table A6-6. Recharge Rates Based on the Chloride Mass Balance Method

Well Identifier	Chloride concentration (mg/L)	Apparent Recharge Rate[a] (mm/year)	
		Rate 1	Rate 2
G-2	6.5	7.8	15.7
UZ-14 (sh)	6.9	7.4	14.8
H-1 (Tcp)	5.7	8.9	17.9
b#1(bh)	10.8	4.7	9.4
c#1	7.4	6.9	13.8
c#2	7.1	7.2	14.4
c#3	7.2	7.1	14.2
c#3('95-97)	6.5	7.8	15.7
ONC#1	7.1	7.2	14.4
p#1(v)[b]	13.0	3.9	7.8
G-4	5.9	8.6	17.3
H-3	9.5	5.4	10.7
H-4	6.9	7.4	14.8
H-5	6.1	8.4	16.7
UZ#16	10.6	4.8	9.6
WT#12	7.8	6.5	13.1

Table A6-6. Recharge Rates Based on the Chloride Mass Balance Method (Continued)

Well Identifier	Chloride concentration (mg/L)	Apparent Recharge Rate[a] (mm/year)	
		Rate 1	Rate 2
WT-17	6.4	7.7	15.5
WT#3	6.0	8.2	16.5

Source: Table A6-1.

[a] Infiltration rates were calculated based on equation (7). Rate 1 is calculated using the lower estimate for Cl^- concentration in precipitation (0.3 g/L); Rate 2 is calculated using the higher estimate (0.6 mg/L). Recharge estimates obtained by the CMB method are based on Table A5-1, Assumption 5.

[b] Approximately 28.6 percent of the water in this sample is from upward flow in the borehole from the carbonate aquifer (Craig and Robison 1984 [DIRS 101040], p. 49).

A6.3.6.6.1 Evidence for the Timing of Recharge from Hydrogen and Oxygen Isotope Ratios

Many of the effects of seasonal and long-term temperature changes on hydrogen and oxygen values in groundwater described in Section A6.3.1.2.1 have been reported for the Yucca Mountain area. Benson and Klieforth (1989 [DIRS 104370], Figure 11) noted a correlation between $\delta^{18}O$ values and the ^{14}C age of groundwaters near Yucca Mountain. Waters are lighter in $\delta^{18}O$ with increasing age between 9,000 and 18,500 years ago, a trend they attributed to the colder temperatures existing at the time the older water was recharged. Variations in the $\delta^{18}O$ compositions of groundwater discharging in the Ash Meadows area at Devils Hole 55-km southeast of Yucca Mountain were preserved in calcites deposited between 570,000 and 60,000 years before the present (Winograd et al. 1992 [DIRS 100094], Figures 2 and 3). These variations were shown to correlate well with known glacial and interglacial episodes during the period of record, with $\delta^{18}O$ decreasing, on average, by 1.9 per mil during glacial periods.

The δD and $\delta^{18}O$ values of regional groundwater samples and perched-water samples at Yucca Mountain are plotted in Figure A6-48. The modern global meteoric water line ($\delta D = 8\,\delta^{18}O + 10.0$) shown on Figure A6-48 is approximately equal to the local Yucca Mountain meteoric water line ($\delta D = 8\,\delta^{18}O + 8.9$) as defined by Benson and Klieforth (1989 [DIRS 104370], Figure 14) from snow samples obtained from Yucca Mountain. Snow samples were used to define the local meteoric water line because these samples were less likely to be affected by evaporation than rain samples, especially samples of light summer rains that can have a substantial fraction of their volume evaporated before reaching the ground. A paleometeoric water line of $\delta D = 8\,\delta^{18}O + 5.0$ was suggested by White and Chuma (1987 [DIRS 108871], pp. 573 to 574) to fit data from the Amargosa Desert and Oasis Valley.

Although considerable variability in δD and $\delta^{18}O$ values is evident in Figure A6-48, much of this variability is attributable to the heavy δD and $\delta^{18}O$ values of the FMW-N samples and the light δD and $\delta^{18}O$ values of the TM samples. The Yucca Mountain groundwaters (YM groupings only) and most perched waters (excluding NRG-7a and one UZ-14 sample) vary in δD by about 13 per mil and in $\delta^{18}O$ by about 1 per mil. The high ^{14}C activities associated with the

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7.9.6 Concluding Remarks

Modeling calcite deposition provides additional evidence for validation of the UZ model. For the mean infiltration rate (5.92 mm/yr), simulations in Figure 7.9-3 are within the range of data for each unit except at the PTn-TSw contact for the more realistic extended-case geochemical system. The contact between two units is where lateral flow may occur, which is not included in the 1-D model. The comparison in Figure 7.9-3 indicates that the validation criterion is to be met. This is because the acceptance criterion is applied only to the mean infiltration rate that is the expected rate and the other rates, representing extremes, would not be expected to simulate actual mean behavior. In addition, the validation is focused on the extended-case geochemical system. The excursion in the model results at the PTn-TSw contact is not important because it is an artifact of the lack of lateral flow in the 1-D model and would not occur in the 3D UZ flow model.

Over a range of 2 to 20 mm/year infiltration rates, the simulated calcite abundances generally fall within the range of calcite observed in the field, which satisfies the validation criterion. The simulated calcite distributions capture the USGS–measured data from the WT-24 well cuttings (DTN: GS021008315215.007 [DIRS 162127]). The 20-mm/year infiltration rate may be the upper bound for WT-24 location, whereas the base-case infiltration rate (5.92 mm/year) used for the flow model gives the closest match to the data. The observed calcite precipitation for the top of TSw occurs mostly in the fractures, which is also captured. The modeling results can provide useful insight into process mechanisms such as fracture-matrix interaction, as well as conditions and parameters controlling calcite deposition. The modeled calcite abundances generally increase with increasing infiltration rate, but become less sensitive to infiltration at higher rates as a result of changes to the geothermal gradient. Between a 5.92 and 20-mm/year infiltration rate, the amount of calcite is not expected to be significantly different in the TSw, a conclusion supported by the similar abundances in WT-24 and SD-6 in the TSw.

One-dimensional simulation is appropriate because both flow and geothermal gradient are primarily vertical. The current observed calcite is formed cumulatively over about 10 million years. A number of uncertainties are involved in the numerical simulation results; the most influential of which are variations of geothermal gradient and infiltration over time. Differences between one-dimensional and three-dimensional flow are much less than the differences in geothermal gradient and infiltration over 10 million years. Agreement between simulated and measured calcite abundance could work to establish the validity of the flow field from and infiltration rates used in the UZ flow model.

7.10 MODEL VALIDATION USING STRONTIUM GEOCHEMISTRY AND ISOTOPIC RATIOS

This section describes the use of strontium (Sr) and strontium isotopic ratios ($^{87}Sr/^{86}Sr$) for validation of the UZ flow model. Validation methodology consists of work presented in peer-reviewed journals, as well as comparison of model results to data collected for pore waters. The criterion for the validation is a qualitative agreement between simulated Sr concentrations and the average of the observations at the same elevation, and an agreement with vertical trends (BSC 2002 [DIRS 160819], Attachment Section I-1-2-5).

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Perched Water Bodies in Arid Environments and Their Role as Hydrologic Constraints for Recharge Rate Estimation: Part 2. The Case of Yucca Mountain

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The formation and temporal evolution of perched water bodies in the Yucca Mountain (YM) site is the focus of this article. Following the approach proposed by Bagtzoglou (2003), recharge rates that would be required to form and sustain perched water bodies with characteristics similar to the known occurrences at YM are estimated through a series of detailed flow simulations. The results were tested for plausibility by comparing with hydrological and geochemical data. The proposed approach is applied with reasonable discriminatory success to a specific geologic cross-section at the YM site, and recharge rates of 0.13, 0.51, and 6.2 mm/yr are calculated for a set of three hydraulic property realizations. However, only the highest recharge rate (6.2 mm/yr) satisfies both hydrological and geochemical constraints. This is in excellent agreement with current estimates by the US Department of Energy.

Keywords: Yucca Mountain, infiltration, hydrologic modeling, recharge, perched water.

Introduction

Yucca Mountain (YM) in southern Nevada is being considered by the US Department of Energy (DOE) as a potential site for the long-term storage of high level nuclear waste. This site has been selected as a candidate high level waste (HLW) repository site because: (1) it is situated in a remote location; (2) the general area is characterized by a low population density; and (3) it is characterized by an up to 700 m thick unsaturated zone (US DOE, 1986). Thus, the proposed repository, at a depth of approximately 300 to 400 m, is considered to be well protected from processes occurring at the surface and the water table. The favorable geochemical and hydrologic environment provided by the unsaturated zone suggests that high fluxes of water may not readily penetrate the repository, thereby keeping at a minimum waste-package degradation rates and release of dissolved spent fuel.

Parts of the repository being located in a localized saturated zone would mean an increase in the rate of corrosion of the containers and dissolution of the radioactive waste. Even if the repository itself were not actually in the saturated zone, a perched water zone nearby could mean accelerated transport rate of radionuclides into the environment in the event of canister failure. This is particularly important since the host rock (i.e., the geologic unit within which the repository is planned to be constructed) is highly fractured. It is well recognized that under saturated—and, under special circumstances, unsaturated—conditions fractures within tuffs similar to those that occur at YM exhibit very fast response times, capable of conveying amounts of water multiple orders of magnitude greater than that, which can be conveyed by the matrix.

The potential for formation of perched water bodies is identified in federal regulations, for example 10 CFR 60.122(c)(23), as a potentially adverse condition for the storage of HLW in a geologic repository. Perched water is common in arid environments. For example, perched water flows from seeps into the U12n tunnel through the zeolitized Indian Trail Tuff at Rainier Mesa, 50 km northwest of YM (Thordarson, 1965; Russell et al., 1987; Wang et al., 1993). Isotopic signatures (δD and δ^{18}O) indicate that the perched waters at Rainier Mesa are similar to modern meteoric waters and result from recharge relatively quickly from local winter precipitation (Russell et al., 1987). Evidence also suggests that waters from the seeps in the zeolitized tuffs are chemically similar to water from the unsaturated zone below the perched water body, but are distinct from shallower waters (Wang et al., 1993).

Perched water bodies tend to be long-term transient features that are formed where there is a contrast in hydrologic properties (Freeze and Cherry, 1979). Contrasts may result from differences between stratigraphic units. For example, hydraulic conductivity at YM tends to decrease with increased welding of the tuff units. Contrasts may also occur due to the juxtaposition of low-conductivity strata adjacent to more permeable and conductive strata along a structural feature such as a fault or other persistent discontinuity. YM is criss-crossed by numerous potentially permeable faults, as can be seen in Figure 1, thus substantially increasing the probability of locally saturated conditions occurring

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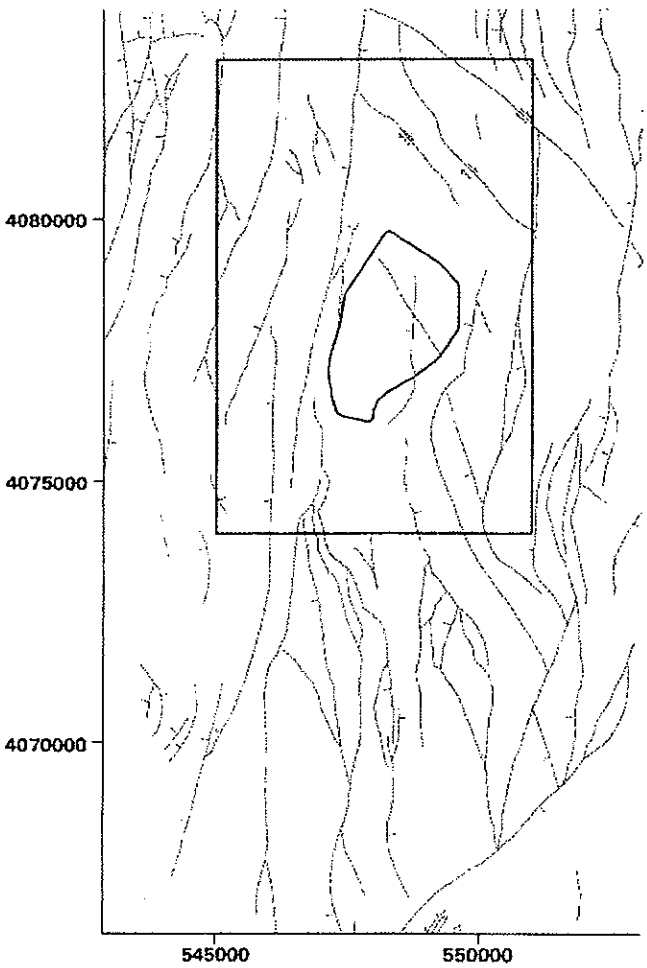


Figure 1. Major faults present in the YM site, as identified in the geologic map by Frizzell and Shulters (1990). The image inner window covers coordinates that range from 545,000 to 551,000 in the x-direction and from 4,074,000 to 4,082,000 in the y-direction. Note that the outline of the proposed repository, indicated in thick solid line, is outdated and is depicted only for georeferencing purposes.

based on the conceptual model presented in the first part of this paper (Bagtzoglou, 2003).

At YM, smectite content increases towards the north; this is likely due to hydrothermal alteration that was associated with the Timber Mountain Caldera (Bish and Aronson, 1993) north of YM. Smectite content also varies with depth, with higher smectite concentrations occurring in fractured, welded tuff (high permeability) above bedded, nonwelded tuff (low permeability). Trends in mineralogy of this type point to areas of focused hydrothermal flow, and help to delineate paleohydrology. High concentrations of clays such as smectite may also serve to create low permeability zones that are favorable to the formation of perched water zones. This may be particularly enhanced at YM, where both higher smectite contents and higher infiltration rates (Flint and Flint, 1994) are found in the northern part of the site.

If perched water bodies formed above the repository, this local saturation could induce localized fracture flow along vertical pathways downward into the repository. Past (and contemporary) occurrence of fracture flow that bypassed part of the unsaturated zone where matrix flow would normally predominate, thus transporting released contaminants at greater flow rates, has been recently inferred by ^{36}Cl measurements at the Exploratory Studies Facility (ESF), within the repository host rock at YM (Fabryka-Martin et al., 1996). Bomb-pulse ^{36}Cl has been identified at a few very distinct, highly fractured zones, generally in the vicinity of faults, indicating that a small amount of water at these locations is less than 50 years old and that it was, most probably, transported preferentially through extremely localized pathways. However, there exists no evidence that these fast pathways are indeed associated with a perched water body that induced this flow pattern in the past.

Although they do exist now, perched aquifers would be more likely to form or expand under wetter, climatic conditions that cause increased recharge flux. Such conditions have existed in the past (i.e., the Pleistocene), and it is possible that perched aquifers at the YM area are relict features formed by higher infiltration rates during former pluvial climates. Perched aquifers may also form where alluvial deposits underlie intermittent stream channels. When ephemeral stream flow saturates the alluvial material, the alluvium may remain saturated long after the stream channel is dry. Even though these perched aquifers would be located near the surface, the water could eventually drain through fractures to the water table below. More importantly, it is possible that water from these perched aquifers could find its way into the host rock by vertical and lateral flow along contacts at or near locations where the repository host rock is exposed. Perched aquifers in alluvial material at YM may be difficult to identify because they are probably infrequent and of short duration. However, like intermittent streams, they have the potential to form, drain, and form again.

Hydrogeologic Setting

The YM site is located approximately 160 kilometers northwest of Las Vegas, Nevada. It is composed of layers of Tertiary volcanic tuff and consists of a series of north-trending fault-block ridges that are generally slightly dipping to the southeast (5° to 10°). The region is in the tectonically active Basin and Range Province, and a number of extensional faults are present within a few kilometers of the proposed repository footprint. Rock units range from densely welded and highly fractured tuffs to less-fractured, nonwelded and moderately welded units. Surficial units are deeply incised with washes, particularly on the eastern flank of the YM ridge. A thin coating of alluvium/colluvium covers much of YM, achieving depths of tens of meters in some of the larger washes. A detailed description of the geologic and hydrologic setting of the YM site follows.

Basin and Range Province

The Basin and Range province extends from southern Idaho and Oregon, where it is bounded on the north by the Columbia

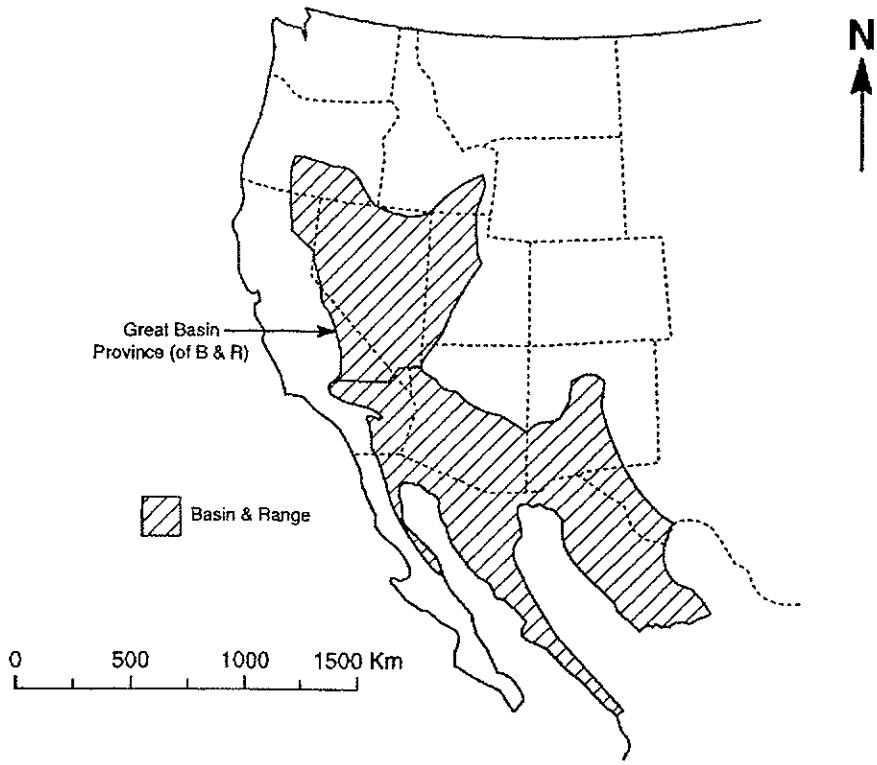


Figure 2. The Basin and Range province and its northernmost section, the Great Basin.

Plateau, 1500 km southward to northern Mexico, where it is bounded on the south by the Sierra Madre (Figure 2). The Basin and Range province has a long and complex geologic history, beginning in the Precambrian and extending into the Holocene. Structures that were produced by more recent geologic events may reflect the influence of an even earlier structural feature (Stewart, 1984). For example, the trend of the current geologic features follows the trends of geologic features produced by earlier geologic events. Plate collisions accreted much of this region onto the then continental margin of the prePaleozoic and Paleozoic North America. Late Paleozoic and Mesozoic events later modified this region. Early Mesozoic subduction of the Kula plate beneath the North American plate produced an Andean-style volcanic range with large scale granitic igneous intrusions that was later exposed to become what we know as the Sierra Nevada batholith. Areas further inland were relatively unaffected by this subduction at that time. A later increased rate of subduction (caused by an increase in Atlantic seafloor spreading rate) did produce structural changes in the Great Basin region, including folding and thrusting along a well-defined belt from Canada to Mexico. This deformation occurred primarily during the Sevier (late Jurassic to late Cretaceous) and Laramide (late Cretaceous to middle or later Eocene) orogenic events and thrust late prePaleozoic and early Paleozoic rocks over late Paleozoic and Mesozoic rocks (Fiero, 1986).

YM is in the Basin and Range province, and more specifically the Great Basin section of the Basin and Range province. The Basin and Range province is divided into five sections, and the Great Basin is the northernmost section (Dohrenwend, 1987). It ranges from southern Idaho and Oregon through most of Nevada and much of western Utah and eastern California (Figure 2). It borders the Colorado Plateau and the middle Rocky Mountains on the east and northeast, respectively, and the Sierra Nevada and the Cascade Range on the west and northwest, respectively, and the Garlock Fault zone to the south. The Great Basin is not, as its name suggests, a large basin; rather it is an elevated region that contains many sub-basins and is flanked on three sides by lower terrain: (1) Bonneville basin on the east, (2) Lahonton basin on the west, and (3) on the south a less well-defined lowland region comprising much of southern Nevada. Except for certain regions in the north, northwest and southeast, all the sub-basins in the Great Basin are closed. In the early to middle Cenozoic, extreme eruptions of silicic volcanic material occurred in the Great Basin region. Igneous activity migrated generally southward during the early to middle Cenozoic; from Washington about 45–59 million years before present (maBP) to central Idaho and northwestern Wyoming about 38–49 maBP, to northern Nevada about 43–33 maBP, and finally to central Utah about 20–34 maBP (Stewart, 1984). While early and middle Cenozoic volcanic activity was widespread over most of the Great Basin, late Cenozoic igneous activity occurred primarily along the margins of the Great Basin

(Stewart, 1984). Alternating layers of welded and nonwelded tuff occur in the vicinity of YM and can typically be traced laterally throughout the area. These layers vary in thickness from tens to hundreds of meters with the major welded ashflow tuffs being usually separated by thinner intervals of nonwelded to poorly welded ashfall and airfall tuffs and reworked tuffaceous material (Wilson et al., 1994). At about 13 to 14 maBP, eruptions from Claim-Canyon cauldron, Timber Mountain-Oasis Valley caldera complex, Wahmonie area, and Crater-Prospector Pass caldera complex produced thick ash flow and airfall tuff that occur in the area of this study (Byers et al., 1989). These layers correspond to eruptions that relate to the collapse of caldera systems (Wilson et al., 1994).

The present structural and geomorphic character of the Basin and Range is a product mainly of the late Cenozoic tensional stresses to which it has been subjected, beginning about 17 maBP. This has produced extension in the region, with most estimates for this extension in the range of between 10% and 35% of the original width of the province (Stewart, 1984). Along with this extension was a regional uplift of as much as about 2,000 m. This extension is manifest in this area by anomalously high heat flow, low upper mantle seismic velocity, low regional gravity field values, and an extensive series of normal faults. The trend of this faulting generally follows previous geologic structural patterns. The northern part of the Great Basin with its well defined, steep, parallel, linear range fronts is contrasted with the southern portion where, along a well-defined east-west line, the character of the topography goes to a more mature terrain, with lower mountains with wide surrounding complexes of pediments and alluvial fans. Fresh fault scarps and active seismicity are uncommon in the southern portion. Whereas the northern portion appears to be a tectonic province of active uplift and extension, the southern region appears to be nearly seismically stable. The tensional forces are generally east-west oriented, producing normal faults that strike roughly north-south. This north-south normal faulting often produces a series of linear north-south trending upthrown blocks (horst) and downthrown blocks (grabens) (Figure 3). The throw of these faults is typically about 2,000 to 5,000 m in the Great Basin region. This large amount of structural relief is typically masked by accumulations of sediment with a thickness ranging from a few hundred meters to more than 3,000 m (Stewart, 1984). Another important way of producing common Basin and Range structures is by the tilting of the structural blocks along listric normal faults (faults that decrease in their dip angle as their depth increases). The product of this tilting along a listric fault is that the upslope portion of the tilted block forms the ridge and the downslope part forms the valley (Figure 4).

Figure 3. Horst and graben structures; the downthrown and upthrown blocks form the grabens and horsts, respectively.

Figure 4. Fault block structures become inclined as they move downward along listric normal faults.

Local Geologic Setting

YM is located at the western edge of the Nevada Test site about 150 kilometers northwest of Las Vegas, Nevada (Figure 5). It is a rather narrow ridge that formed as a result of being the upthrown block relative to the downthrown blocks on either side of it. It trends roughly north-south and is tilted between 5 to 10° to the south-southeast. The western edge is bounded by the Solitario Canyon Fault, and just west of the fault is Solitario Canyon, which is about 180 m lower in elevation than the crest. The eastern side is dissected by a series of washes running east to southeast toward Jackass Flats, which is about 460 m below the crest. YM is also cut, primarily in the east, by a series of mostly north-south striking normal faults, which are upthrown to the east. Between this series of faults on the east, the Solitario Canyon Fault on the west, and the right lateral strikeslip shear zone in Drill Hole Wash to the northeast, exists a roughly triangular region that is relatively less complex structurally than the surrounding area. This region is known as the central block of

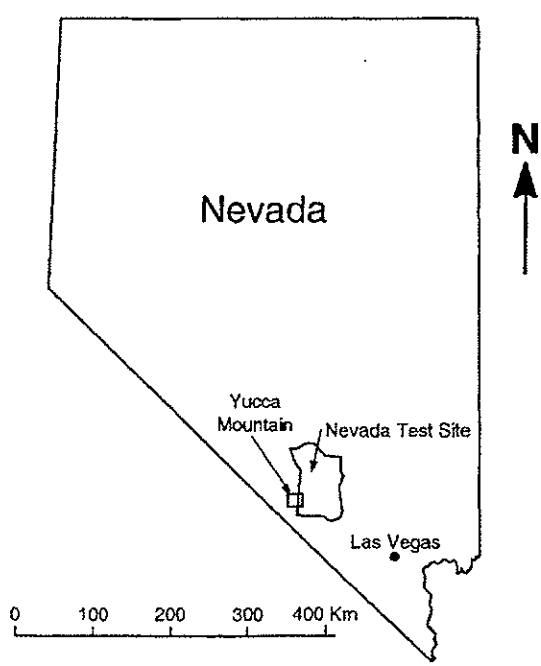


Figure 5. Location of Yucca Mountain, the site of the proposed high-level nuclear waste repository in southern Nevada.

YM. Two significant faults run through the central block. These faults are the nearly vertical Ghost Dance normal Fault, which strikes north-south, and the right lateral Sundance Fault, which strikes, northwest-southeast.

YM is composed primarily of volcanic tuffs of Miocene age. The tuff layers range from densely welded and highly fractured to less fractured and nonwelded to moderately welded. A thin cover of alluvium/colluvium overlies most of YM, and in some of the larger washes it accumulates to depths of tens of meters. Three formations occur in the unsaturated zone of YM. These are, in ascending stratigraphic order, Crater Flat Tuff, tuffaceous beds of the Calico Hills, and the Paintbrush Tuff. Hydraulic properties of the rocks are related more to their physical characteristics, which are largely dependent upon the degree of welding, than to their petrographic characteristics. Hydraulic boundaries based on physical properties (due to the degree of welding) do not necessarily correspond to boundaries based on petrographic characteristics. The tuffs are variably fractured and although the more densely welded tuffs have a lower porosity, they are generally more densely fractured. The Center for Nuclear Waste Regulatory Analyses (CNWRA) staff has grouped the rocks according to hydrogeologic properties. The names and descriptions of the rock unit divisions are given in Stirewalt et al. (1994) and discussed below. The Tiva Canyon Member of the Paintbrush Tuff is moderately to densely welded and comprises the *Tiva Canyon welded Tuff*. Undifferentiated formations of the upper Paintbrush Tuff and part of the lower Tiva Canyon Member are nonwelded to partially welded tuffs and comprise the *Paintbrush nonwelded Tuff*. The Topopah Spring Member of the Paintbrush Tuff comprises the *Topopah Spring1, 2, 3 welded Tuffs*. The upper portion of this member is composed of moderately to densely welded, lithophysae-rich ashfall tuffs. The lower portion is composed of moderately to densely welded, lithophysae-poor ashfall tuffs and a basal vitrophyre. This study considers the Topopah Spring1, 2, 3 welded Tuffs as one stratum. Undifferentiated Calico Hills Tuffs, lower Paintbrush Tuff and Upper Crater Flat Tuff are nonwelded ashfall and bedded tuffs, and these comprise the *Calico Hills nonwelded Tuff*. The moderately welded ashfall tuffs of the Prow Pass Member of the Crater Flat Tuff form the *Prow Pass welded Tuff*. Undifferentiated Upper Crater Flat Tuffs, including the Lower Prow Pass and the Upper Bullfrog Member, form the *Crater Flat undifferentiated nonwelded Tuff*. These members are zeolitic and nonwelded to partially welded ashfall and bedded tuffs. The Bullfrog Member of the Crater Flat Tuff is moderately to densely welded ashfall tuffs and forms the *Bullfrog welded Tuff*. The repository is intended to be positioned deep within the relatively dry, unsaturated Topopah Spring welded Tuff, about 300–400 m below the ground surface and approximately 250 m above the water table (US DOE, 1988).

In addition to the presence of markedly distinct geologic units and tectonic faults, the geologic units are also variably fractured. For example, the Topopah Spring welded unit, where the proposed repository is to be located, is a low-porosity welded tuff believed to be densely fractured, while the underlying Calico Hills, nonwelded-vitric or zeolitized unit is a higher porosity, nonwelded tuff with seemingly much lower fracture density (US DOE, 1988).

Climate

This region has currently an arid climate and receives a mean annual rainfall of about 150 mm/yr, nearly 75% of which occurs from October through April as frontal systems move through the region. Warm season precipitation usually occurs as brief, intense thunderstorms. Many relict landforms and sedimentary deposits in the Basin and Range province indicate a previous climate that was much different than today. For example, cirques, nivation hollows, and glacial moraines are found, as are fluvial and beach deposits. From a relatively noisy background of tectonic, lithologic, and evolutionary influences, the influences of climatic change are difficult to filter out. Many studies have been conducted on the paleoclimate of the American Southwest, but the results are usually only in partial agreement or even directly contradictory. For example, full-glacial conditions from different studies range from cold and dry to mild and wet. Estimates of full-glacial mean annual temperature range from 2.8 to 16°C colder than present, and full-glacial mean annual precipitation estimates range from 50% to approximately 200% of present levels. Although some of this variation can certainly be attributed to different approaches and assumptions, a substantial part of the differences is almost certainly due to the specific areas of the different studies being affected differently, both in magnitude and in character, by the changing regional climate. Some basic characteristics of this regional climatic change, however, do seem to be constant throughout most of the region. For example, during the period between about 25 and 12 thousand years before present (kaBP) pluvial lake levels were high to intermediate, after which time they declined rapidly and were low to dry between approximately 10 to 5 kaBP. Furthermore, pinyon-juniper woodlands were present at approximately the same time as the high lake levels in areas where now only desert scrub communities exist. Finally, the effective moisture of the latest Pleistocene and the earliest Holocene was significantly greater than the present-day effective moisture.

Spaulding (1985) conducted research with plant microfossils and dated remains found in packrat middens in the vicinity of the Nevada Test site. Based on this work, Spaulding (1985) reported that the climatic conditions at the Nevada Test site about 45 kaBP were very similar to the present-day conditions in northern Nevada. Figure 6 summarizes precipitation and temperature changes for a base, an upper bound, and a lower bound case for the past 45,000 years near the Nevada Test site as inferred by analyzing original data reported in Spaulding (1985). Three distinct precipitation and temperature regimes can be identified: (1) 45 to 39 kaBP is a period of decreased temperature when precipitation increased from present levels to 15% greater than present; (2) 38 to 18 kaBP is a period when precipitation varied from 16 to 40% greater than present, with temperatures from 3–6°C cooler than present; and (3) a definite warming period

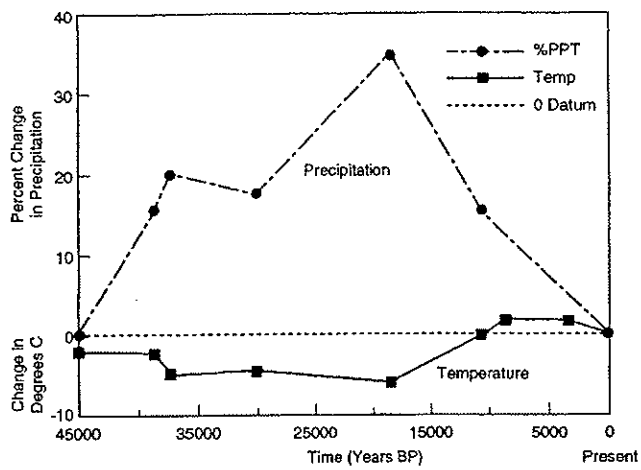


Figure 6. Precipitation and temperature changes from present conditions for the past 45,000 years in the vicinity of the NTS. Based on original data from Spaulding (1985).

from 18 to 13 kaBP to present, in which precipitation declined back to present-day levels while temperature increased by 4°C. The lower temperature and greater precipitation of the past pluvial climate that are shown in Figure 6 indicate that a significantly greater infiltration and groundwater recharge probably occurred during that time. Even though it is fair to speculate that most of this recharge occurred in the areas of higher elevation north of YM, it is hypothesized that water was also able to find its way down in the area of the proposed repository more rapidly and in greater quanities than at present. Calcite deposits that are thought to have been formed from the main aquifer exist above the present water table. This suggests that the water table has been higher in the YM region than it is today by approximately 115 m (Quade and Mifflin, 1995). Qualitatively similar observations were made by Geyh et al. (1995) for the Nubian sandstone near the river Nile, which has been estimated to have fallen in stages approximately 60 m since the climate changed from a prolonged pluvial period to an arid one (about 6 to 4 kaBP). Czarnecki (1985), following a numerical modeling approach, investigated the effects a wetter future climate would have on the water table and concluded that a 100% increase in precipitation could cause the water table at YM to rise by as much as 130 m. Such a rise in the water table would not be adequate to inundate the repository, located 250–300 m above the current water table, but saturation levels above the higher water table would see an increase from present-day values.

Finally, the net annual infiltration from rainfall and surface water over YM has not been definitively determined yet, but several estimates do exist. They vary from 3.0 to 35.0 mm/yr with an average of 14 mm/yr (Stothoff et al., 1995; Stothoff, 1997), to 2.0 to 20 mm/yr with an average of 5 mm/yr (Bodvarsson et al., 1999), from a mean annual rainfall of about 150 mm/yr. These mean values do not take into account the more extreme rainfall rates that may occur due to interannual and interseasonal fluctuations and individual storms. In addition, these values only reflect contemporary rainfall and infiltration conditions. Under ambient conditions, it is likely that radionuclides released from the repository zone will be transported predominantly in the unsaturated flow regime. However, locally saturated flow conditions may also occur in the vadose zone, possibly due to short and intense rainfalls, or due to extremes in climatic fluctuations on larger time scales, or due to repository-induced elevated temperatures (Ofoegbu et al., 1999, 2001; Buscheck et al., 2002).

Review of Shallow Infiltration Studies at Yucca Mountain

The amounts, timing, and locations of infiltration are controlling factors in the movement of groundwater throughout the site and, therefore, control the formation and temporal evolution of perched water bodies. In fractured, unsaturated rock, such as that found at the YM site, occurrence of infrequent, high-intensity rainfall events may modify, perhaps drastically, the subsurface flow regime from the one predicted by assuming that all rainfall events have average intensities. Indeed, the DOE has concluded that the spatial and temporal distribution of infiltration may be the most important factors influencing groundwater flow path development (US DOE, 1992). Deep percolation fluxes are affected by processes active in the near-surface zone, including evaporation, transpiration, liquid water flow, and vapor flow. Each of these processes is governed by several factors. For example, precipitation has been found to vary substantially over the YM region, both spatially and temporally, and winter storms are, in general, more uniform and of longer duration than summer storms (Hevesi et al., 1992a, 1992b, 1994). These observations indicate that, especially for summer storms, a spatially uniform precipitation pattern is clearly not applicable, even at the site scale. Similarly, evaporation from the ground surface is affected by air temperature, atmospheric vapor pressure, wind speed profile, incident solar radiation, surface soil and rock texture, plant activity, surficial temperature, and surficial moisture content.

The sensitivity of long-term net infiltration to each infiltration-affecting factor was first estimated using detailed numerical simulations of the shallow subsurface (Stothoff et al., 1995; Stothoff, 1997). The calculated sensitivity is generic, thus is not dependent on a particular spatial location. Then, each of the infiltration-affecting factors was evaluated on a fine grid over the entire YM area. Potential infiltration-affecting parameters include air temperature, atmospheric vapor pressure, wind speed profile, incident solar radiation, surface soil and rock texture, plant activity, surficial temperature, and surficial moisture content, all of which may vary widely both in space and time. Finally, the calculated sensitivity information was used to estimate net infiltration over the fine grid. The numerical simulator, BREATH (Stothoff, 1995), was used to calculate flow in 1D columns. At the bottom boundary of each column, a zero-saturation-gradient (unit-head-gradient) boundary condition was applied to simulate gravity drainage. At the top boundary of the column, the simulator was presented with 10 years of meteorological inputs on an hourly basis, based on hourly readings from the Desert Rock,

NV, National Weather Service meteorological station located approximately 30 miles to the east of YM (National Climatic Data Center, 1994).

In order to estimate the spatial distribution of infiltration, the YM area was subdivided into three classes: (1) alluvium, (2) fractured welded bedrock overlain by alluvium, and (3) nonwelded bedrock. The alluvium within the Scott and Bonk (1984) outline covers about 31% of the total site area. Based on the CNWRA 3D Geologic Framework Model (GFM) (Stirewalt and Henderson, 1995), welded-tuff bedrock underlies 64% of the remaining area, while nonwelded tuffs are exposed in the remaining 5%. Based on alluvium distributions resulting from nominal source term parameters and corrected with the empirical slope-dependent alluvium depths within the Scott and Bonk (1984) alluvium outline, the infiltration distribution is calculated using the base case alluvium and fracture properties. The average infiltration over the YM site area (6 km E-W × 9.5 km N-S) was found to be 14.0 mm/yr, while within the 3 km E-W × 4.5 km N-S window surrounding the proposed repository footprint the average infiltration was found to be 15.6 mm/yr. In general, the coefficient of variation (CV) for pixel-by-pixel (30 × 30 m) infiltration was found to be larger for the subregional area than for the repository box, suggesting that infiltration patterns are more uniform within the proposed repository footprint than over the region as a whole.

The largest Annual Average Infiltration (AAI) tends to be on sideslopes, whereas in the wash bottoms little or no AAI is predicted. It is plausible to assume that there could be enhanced AAI at the foot of the sideslopes due to overland flow of runoff; there may also be additional AAI within the intermittent stream channels within the washes. The predicted areally averaged AAI rates range from 3 to 45 mm/yr (Figure 7a). As a comparison, USGS estimates of infiltration within the proposed repository footprint were on the order of 25 mm/yr (Flint et al., 1995), and current DOE estimates range from 2 to 20 mm/yr (Bodvarsson et al., 1999). Similar recharge estimates were obtained by Wood and Sanford (1995) for the semiarid Southern High Plains of Texas and New Mexico. Their analysis was based on the chloride mass-balance method and, even though it dealt with completely different materials, average recharge estimates of approximately 11 mm/yr were obtained.

Perched Water Body Occurrences at Yucca Mountain

A number of perched zones have been found at several boreholes (USW UZ-1, UZ-14, NRG-7a, SD-7, and SD-9) at YM (Burger and Scofield, 1994; Yang et al., 1996; Wu et al., 1999). A vacuum-reverse-air-circulation drilling method was used for these boreholes to prevent contamination from drilling fluids, and all perched water samples were collected using plastic or stainless-steel bailers. All perched water found occurs in the upper Calico Hills unit, with the exception of UZ-14 and USW SD-9, where the perched water body is found on the basal vitrophyre in the Topopah Spring unit. Boreholes UZ-1 and UZ-14, which are on the same drilling pad, encountered a perched zone at a depth of 190 m above the water table. The zone was extensive enough to be pump-tested at a rate of 0.204 m^3/h for 67 h, and a total of 22.71 m^3 was produced. It has been estimated, however, that this perched water zone is much more extensive than originally thought, with an approximate volume of 114,000 m^3 (Yang et al., 1996). In USW SD-9, perched water appeared to be just above the basal vitrophyre of the Topopah Spring unit, 120 m above the water table. Boreholes that encountered perched water within the Calico Hills Tuffs include USW SD-7 and USW NRG 7/7a. The perched zone encountered by SD-7 was extensive enough to be pump-tested at a rate of 0.75 m^3/h for 30 h, and a total of 45.42 m^3 was produced. This perched water zone is a relatively small body and its total volume has been estimated at approximately 300 to 500 m^3. Figure 7b depicts the location of all boreholes in the vicinity of the proposed repository (even boreholes that were not studied explicitly for perched water occurrence) together with an outline of the now completed ESF tunnel. Finally, Figure 7c presents a geologic cross-section through all boreholes identified in Figure 7b.

Within 6 to 8 m sampling intervals in the five boreholes large ^{14}C variations are detected, ranging from 27.2 to 66.9 Percent Modern Carbon (PMC) with an average of about 37 PMC, indicating a multitude of water sources that contribute to these perched water reservoirs. The apparent (uncorrected) ^{14}C ages of perched water range from 3,500 to 10,800 years, as indicated by $\delta^{13}C$ data (Yang et al., 1996) accounting for caliche dissolution. The uncertainty in ^{14}C measurements is ± 0.7 PMC (Yang et al., 1996).

Correlation Between Perched Water Occurrences and Shallow Infiltration Distribution at Yucca Mountain

Identifying any association between the nature of potential flow pathways and the evidence of flow based on geochemical and hydrological data is a challenging task. For example, Figure 7a presents a preliminary attempt of correlating the shallow AAI spatial distribution and existing geologic structure with known evidence of perched water occurrence at the YM site. Several observations can be made from this figure. First, there is a reasonable correlation between high AAI values and known perched water occurrences. This is particularly evident when keeping in mind the general southeast dipping trend of the strata, which would force the initially vertical infiltration to be diverted laterally along dip. Second, there appears to exist another important correlation between known perched water occurrences and significant structural features, such as faults or fracture zones. Third, Figures 7a and 7b provide little information to corroborate the link between spatial distribution of AAI, which is estimated at a depth of only 30 m, tectonic features, which may (or may not) cross stratigraphic boundaries, extending upward to the ground surface, and known perched water occurrences at great depths. Existence of such correlations at depth (i.e., where the perched water has been found) would be of great significance because it implies that rapid movement of water from the surface requires discrete, transmissive features extending from

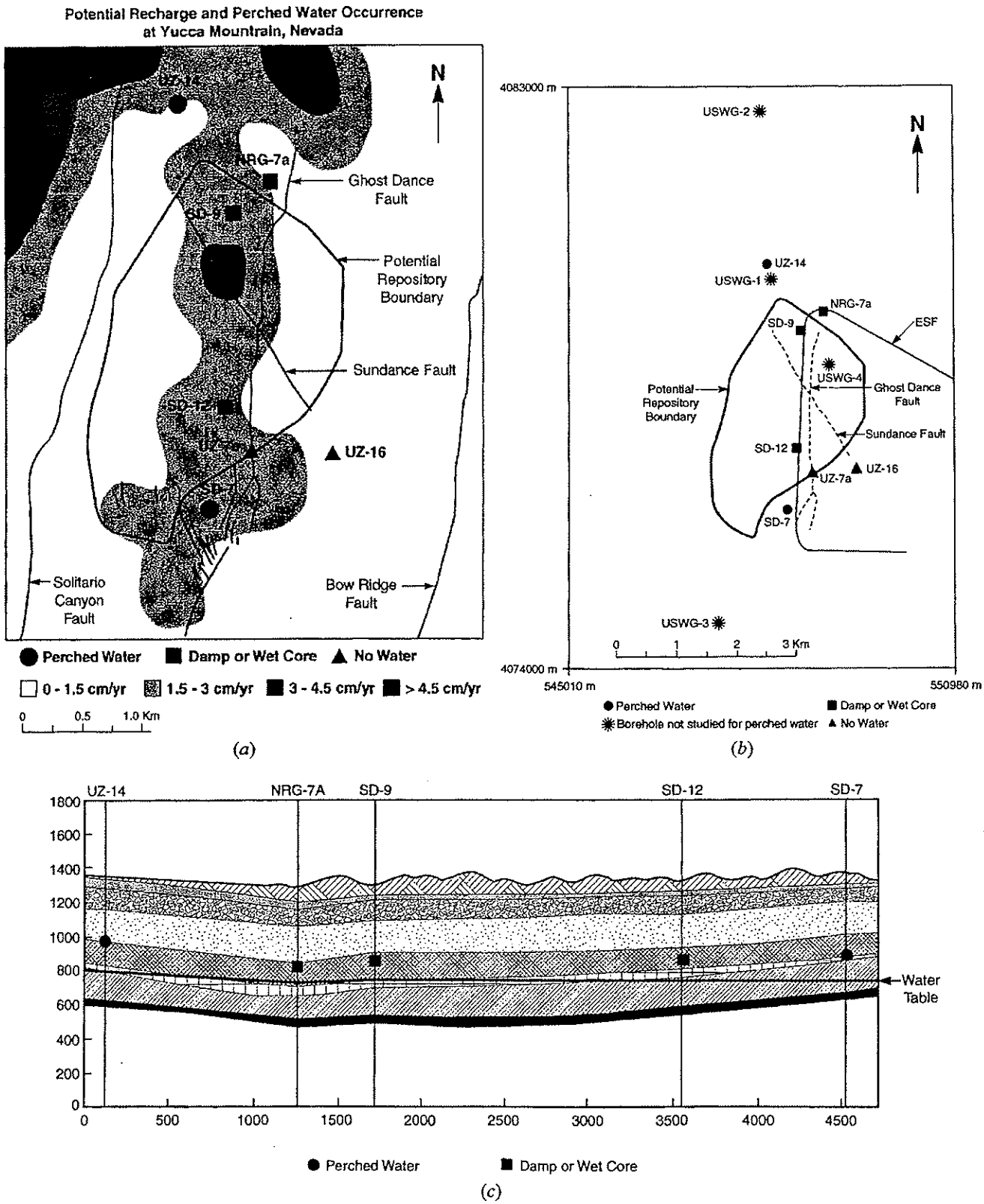


Figure 7. (a) Distribution of smoothed AAI at the YM site, as calculated by Stothoff et al. (1995) at a depth of 30 m, and major faults present. Borehole-associated symbols serve to provide information regarding the occurrence, or not, of a perched water body at each individual borehole. (b) Location of all boreholes in the YM site vicinity, together with ESF outline for georeferencing purposes. (c) Geologic cross-section through YM boreholes. Note that the outline of the proposed repository, indicated in thick solid line, is outdated and is depicted only for georeferencing purposes.

the surface to great depths. Therefore, an effort to provide the missing link and correlate AAI values with known perched water occurrences at depth was deemed necessary.

Perched Water Body Modeling at Yucca Mountain

Faults in YM are common, and this faulting has produced offset of the stratigraphic units. If the offset of the fault is such that a relatively permeable unit within the downthrown fault-block is juxtaposed against a relatively impermeable unit downdip of the fault, then the channeled water will be inhibited from continuing downdip and will eventually become trapped at this location. Therefore, the modeling methodology presented in the first article (Bagtzoglou, 2003) is applicable for the case of YM.

Modeled Area

The first step towards enhancing modeling efforts is to construct a 3D GFM that embodies the current level of understanding of YM by including lithostratigraphy, hydrostratigraphy, and geologic structure (Stirewalt et al., 1994; Stirewalt and Henderson, 1995) of the pertinent region. Lithostratigraphy and geologic structure are based on surface geologic maps of the site (Scott and Bonk, 1984). Subsurface geology is constrained by both borehole control and through the construction of balanced cross sections (Young et al., 1992). Hydrologic properties include porosity, saturated hydraulic conductivity, and water content. For the hydrostratigraphic model, mean values for hydrologic properties are assigned as constant values for each of seven different lithostratigraphic units. Original data are from DOE site characterization activities (e.g., Craig and Reed, 1991; Flint and Flint, 1990; Loscot and Hammermeister, 1992; Whitfield et al., 1993).

The area considered for the current work is the vicinity of the intersection of the Ghost Dance Fault and the Sundance Fault in the repository area of the YM site (Figures 7a and 7b). The modeled area, a 2D cross-section depicted in Figure 8a, is 1100 meters wide by 650 meters deep and is extracted electronically from the GFM. The plane of view is the plane of the Sundance Fault facing northward. The area of interest is above the water table and primarily updip of the Ghost Dance Fault. The right border of this model represents an artificial no-flow boundary that causes water to accumulate, whereas in reality the water would continue flowing downdip past this boundary if no fault were present. However, given the abundance of normal faults in the YM area, this condition may be a representative depiction since it corresponds to a periodic boundary condition, namely a fault existing every so many length units. Any perching to the right of the fault is eliminated from subsequent calculations. The tuff beds that we are dealing with are (from top to bottom): (1) Tiva Canyon welded (TCw), (2) Paintbrush Tuff nonwelded (PTn), (3) Topopah Spring welded 1,2,3 (TSw), (4) Calico Hills nonwelded (CHn), and (5) Prow Pass welded (PPw).

The computational grid used in this work is rectangular with a $\Delta x = 20$ m and $\Delta z = 10$ m, and an automatic time stepping is invoked. The left and right boundaries are no-flow, the top boundary is constant flux, and the bottom boundary is a water table condition (Figure 8b).

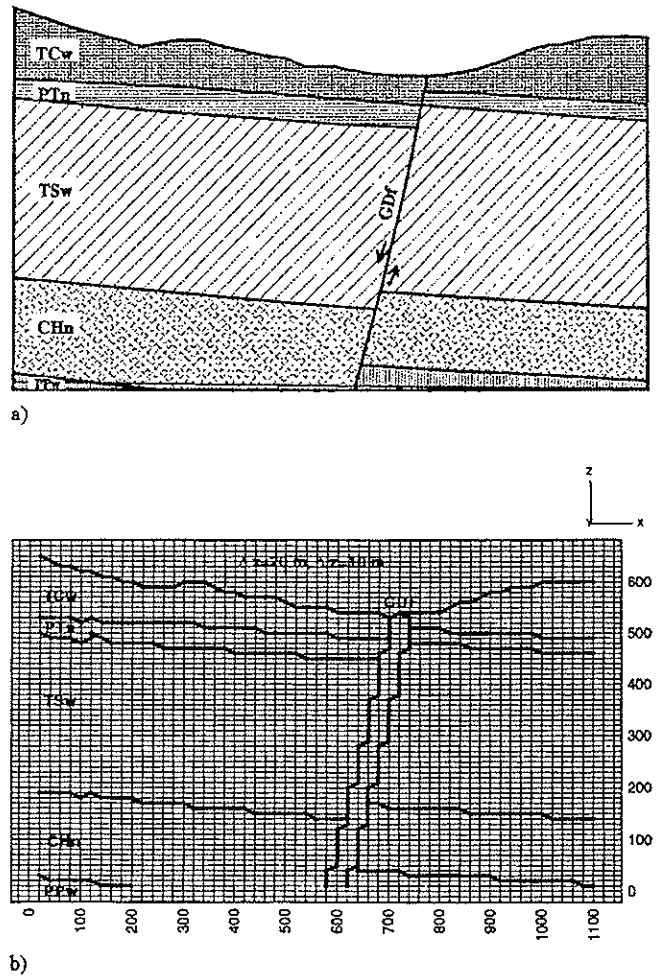


Figure 8. Modeled area. (a) Hydrogeologic units and structural features identified and (b) computational grid used in the simulations. Note that the water table coincides with the bottom boundary and is almost horizontal. TCw, Tiva Canyon welded; PTn, Paintbrush Tuff nonwelded; TSw, Topopah Spring welded; CHn, Calico Hills nonwelded; PPw, Prow Pass welded; GDF, Ghost Dance Fault.

Variability in Hydrologic Properties and Latin Hypercube Sampling

Only limited information is available regarding the spatial variability of hydrologic properties of the volcanic rock units at YM, Nevada. Even though deterministic (geologically controlled) vertical trends in degree of welding within individual units have been identified, insufficient data are available at present to justify using these trends in flow and transport simulations (Istok et al., 1994). Yet, there exists substantial variability in the hydrologic properties, which must be accounted for. Broxton et al. (1993) and Istok et al. (1994) reported coefficients of variation for porosity ranging from 10 to 43%, for permeability ranging from 55 to 75%, and for the logarithm of saturated hydraulic conductivity ranging from 19 to 39%. Ideally, to make the best

final probability estimate for the perching potential, an infinite number of combinations of hydraulic conductivity to saturation level and different saturation levels of different beds should be considered. For each of these combinations the areal extent of the region likely to become perched should be calculated. As discussed in the first part of this paper, in order to obtain sufficiently accurate results without using all possible combinations, a statistical method known as the *Latin Hypercube Sampling* (LHS) was employed to determine the overall probability of the site developing localized perched water zones.

The numerical procedure of estimating the recharge rate that would sustain a perched water body, of specified volume and PMC, can be repeated for as many LHS property set replicates. By calculating statistics on the inferred recharge rate, one could make assertions regarding the variability in this rate and its sensitivity to the hydrologic property variability.

Data

The data used in this study were adopted from the 1993 Total System Performance Assessment (TSPA-1993) for YM (Wilson et al., 1994). Even though it is recognized that there exist more complete data sets, the work presented here is of a methodological and demonstration nature. TSPA-1993 uses 10 hydrogeologic units. Because the GFM model of the YM site used here employs slightly different stratum classifications, some modifications were necessary. Some units are directly equivalent and others were combined by a weighted average based on their relative thicknesses. The Topopah Spring vitrophyre from the TSPA-1993 was not used because it is not continuous over the entire modeled area, and there exists great uncertainty regarding its extent and thickness. The Bullfrog and Tram units were also not used because they lie completely below the main water table in the modeled area. The correlation between the TSPA-1993 division and the current study division are summarized in Table 1.

From the TSPA-1993 data (mean, minimum, maximum, and coefficient of variation), a random sampling of possible values from a beta distribution curve were produced using the LHS approach (Iman and Shortencarier, 1984). The particular data sets used thus far in the study are the mean values, the mean values produced by an entropy-fit procedure, and the third of the fifty random realizations produced by the LHS process. The entropy-fit procedure is used when data are sparse and no physical restrictions exist on the range of the parameters (e.g., porosity must be between 0 and 1). A beta distribution was fitted using a nonlinear optimization entropy-fitting procedure that attempts to use a limited sample to determine properties for an entire population. The values for each of these realizations are listed in Tables 2, 3, and 4. Note that porosity and residual saturation values do not change for these data sets, as there typically exists significantly less uncertainty and spatial variability for the aforementioned parameters. Figure 9 depicts typical results of the 50 LHS-based Monte Carlo realizations for the moisture retention characteristic curve together with the mean value and entropy-fitted mean value characteristic curves.

Table 1. Correlation between TSPA-1993 and current study stratum classification

Unit	TSPA-1993	Unit	Current study
1	Tiva Canyon welded	1	Tiva Canyon welded
2	Paintbrush nonwelded	2	Paintbrush nonwelded
3	Topopah Spring welded	3	Topopah Spring welded
4	Topopah Spring vitrophyre		N/A
5	Calico Hills/Prow Pass nonwelded vitric	4	Calico Hills nonwelded
6	Calico Hill/Prow Pass nonwelded zeolitic		N/A
7	Prow Pass welded	5	Prow Pass welded
8	Bullfrog welded		N/A
9	Bullfrog nonwelded		N/A
10	Tram		N/A

Table 2. Matrix property values taken from TSPA-93 (mean)

Rock unit type	Porosity	K_{sat} (m/s)	Residual saturation	van Genuchten parameters α (m^{-1})	van Genuchten parameters n
TCw	0.087	3.86×10^{-1}	0.021	0.0218	1.622
PTn	0.421	5.470×10^{-7}	0.154	0.2485	2.611
TSw	0.139	2.37×10^{-10}	0.045	0.0299	1.730
CHn	0.319	6.220×10^{-9}	0.113	0.0306	2.087
PPw	0.292	2.580×10^{-9}	0.069	0.0180	7.014

Results and Discussion

The volume of perched water should approach a constant value, V_{pres}, starting from an initial maximum represented by V_{max} in Figure 4 of the first part of this paper, within a time frame that is consistent with the climatic change described in Figure 6, namely 20,000 years. Moreover, the value of PMC for the perched water body, as calculated by Equation (12) of the first part of this paper, should approach a target value, PMC_{pres}, consistent with measurements within the same time period.

The first realization used the mean values from the TSPA-1993. As the system began to drain, with no flux added and an initial uniform head value of -10 m, water began to drain from some areas and accumulate in others. The PTn unit, having a high permeability, allowed water to flow freely down through it.

Table 3. Matrix property values taken from TSPA-93 (entropy-fit mean)

Rock unit type	Porosity	K_{sat} (m/s)	Residual saturation	van Genuchten parameters α (m^{-1})	van Genuchten parameters n
TCw	0.087	2.04×10^{-11}	0.021	0.0079	1.622
PTn	0.421	3.800×10^{-7}	0.154	0.5560	2.371
TSw	0.139	2.09×10^{-11}	0.045	0.0136	1.799
CHn	0.319	3.78×10^{-10}	0.113	0.0133	1.959
PPw	0.292	9.12×10^{-10}	0.069	0.0160	5.888

Table 4. Matrix property values sampled by LHS and using TSPA-93 statistics

Rock unit type	Porosity	K_{sat} (m/s)	Residual saturation	van Genuchten parameters α (m^{-1})	van Genuchten parameters n
TCw	0.087	1.88×10^{-10}	0.021	0.00045	1.393
PTn	0.421	2.21×10^{-7}	0.154	0.21112	1.841
TSw	0.139	1.74×10^{-11}	0.045	0.25927	1.851
CHn	0.319	8.88×10^{-10}	0.113	0.03722	3.539
PPw	0.292	5.48×10^{-9}	0.069	0.0160	5.888

When it encountered the TSw unit, which has a low permeability, its downward flow was inhibited. This caused the water to be channelled downdip in the PTn until it reached the Ghost Dance Fault. The footwall of the fault has been uplifted such that the PTn in the hanging wall is juxtaposed against the relatively impermeable TSw unit in the footwall of the fault. This produces a trap where the water that is channelled downdip through the PTn encounters the relatively impermeable TSw at the fault and begins to accumulate, producing a perched water body. As it continues to accumulate, it percolates slowly downward through the TSw unit, thus extending the perched water body well in the TSw unit. The perched body in the PTn and TSw units continues to grow as long as there is enough water above it to supply it with water faster than it can be dissipated. It reaches a maximum perched water volume of 15,949 m^3 at 455 years (Figure 10), after which the perched water begins to dissipate until it is completely drained by about 1,600 years. Note that a threshold of 99.9% has been applied to the saturation contours in order to make the outline of the perched water body more clear.

Starting from the point in time with maximum perched water volume, a flux was added at the surface to approximate a mean

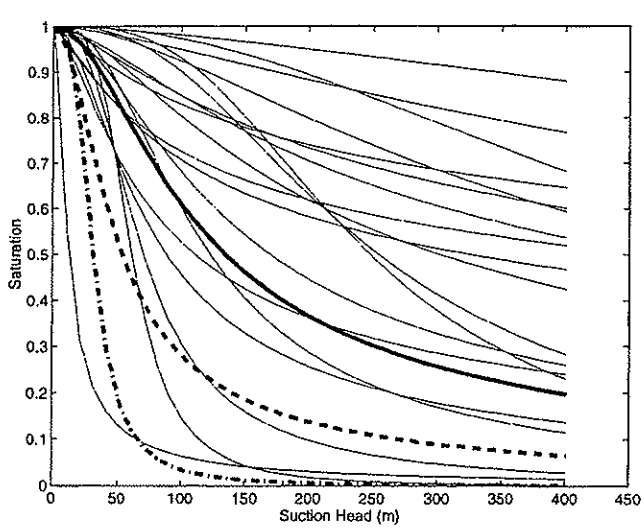


Figure 9. Moisture retention characteristic curves for 50 LHS-generated random realizations (thin solid line), analyzed realization (thick solid line), TSPA-based mean values (thick dash-dotted line), and TSPA-based entropy-fitted mean values (thick dashed line).

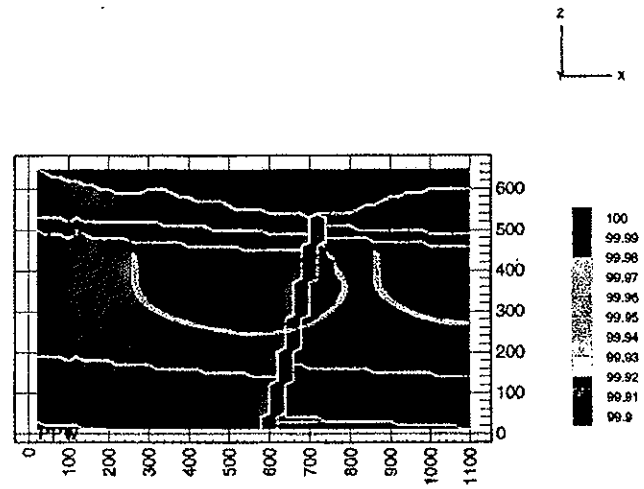
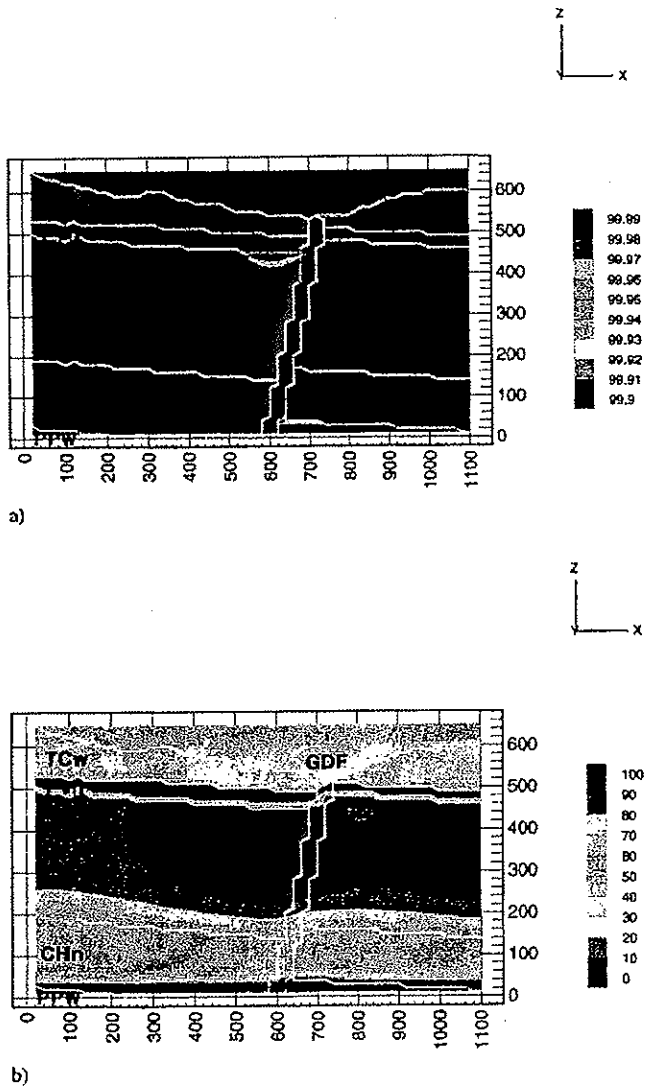


Figure 10. Contour plot of saturation after 455 years of a draining simulation, at which point a maximum perched water volume of 15,949 m^3 has been attained. Note that a threshold of 99.9% is applied to the saturation contours. TCw, Tiva Canyon welded; PTn, Paintbrush Tuff nonwelded; TSw, Topopah Spring welded; CHn, Calico Hills nonwelded; PPw, Prow Pass welded; GDF, Ghost Dance Fault.

infiltration rate. This was allowed to continue until the system reached an equilibrium condition, specifically until the perched water body disappeared or remained at a constant volume. Different flux rates were added until one was found that produced and sustained a perched water body of roughly the same volume of water as actual perched water bodies found in the area (e.g., SD-7), approximately 400 to 500 m^3. In this case, a constant flux of 6.2 mm/year applied uniformly to the top of the system produced a sustained perched water volume of 528 m^3 (Figure 11a) right below the PTn/TSw interface. Figure 11b depicts the exact same saturation field without any threshold application activated; the range of saturation values present throughout this specific cross-section of YM is evident here. Figure 12 depicts the temporal evolution of the perched water volume for the draining simulation, and the simulations with a recharge of 6.2 and 8.0 mm/yr, respectively. Note how the 8.0 mm/yr simulation diverges and floods the system, whereas the 6.2 mm/yr simulation reaches the desired volume asymptotically.

The procedure that used the entropy-fit mean values was used on the realization, and the same general behavior of the water movement was observed. The water drained downward through the more permeable PTn until it encountered the relatively impermeable TSw unit and was channelled downdip until it encountered the TSw unit across the Ghost Dance Fault. At this point the water became trapped and formed a perched water body that expanded downward into the TSw unit. In this realization, however, it proceeded at a much slower rate, and the flux needed to create a sustained perched water body was substantially less than what was required in the previous realization. Under draining conditions, the perched body reached its maximum volume of 8,300 m^3 at about 2,759 years, and by 6,350 years it had completely dissipated. A flux of 0.51 mm/yr produced a sustained perched volume of about 555 m^3 (Figure 13).



a)

b)

Figure 11. Contour plot of saturation after 455 years of draining and 7,155 years of applying an infiltration rate $q = 6.2$ mm/yr with (a) a threshold of 99.9% applied to the saturation contours and (b) no threshold applied to the saturation contours. TCw, Tiva Canyon welded; PTn, Paintbrush Tuff nonwelded; TSw, Topopah Spring welded; CHn, Calico Hills nonwelded; PPw, Prow Pass welded; GDF, Ghost Dance Fault.

Finally, the same procedure was repeated for one of the 50 LHS-generated random realizations. Because of the properties of the top layer (TCw) and the assumed initial head level of −10 m, this layer was saturated at the very beginning of the simulation and then began to drain. This is the reason for a high initial saturated volume. After this condition disappeared and the saturated volume reached a low of about 926 m^3 at 10 years, the volume began to accumulate again as the water drained from some locations and became trapped in other locations. The maximum volume of 3,676 m^3 was attained at about 8,000 years after the draining began. At about 25,000 years the saturated region had completely dissipated (Figure 14). In the first two realizations, the starting point for all simulations of a

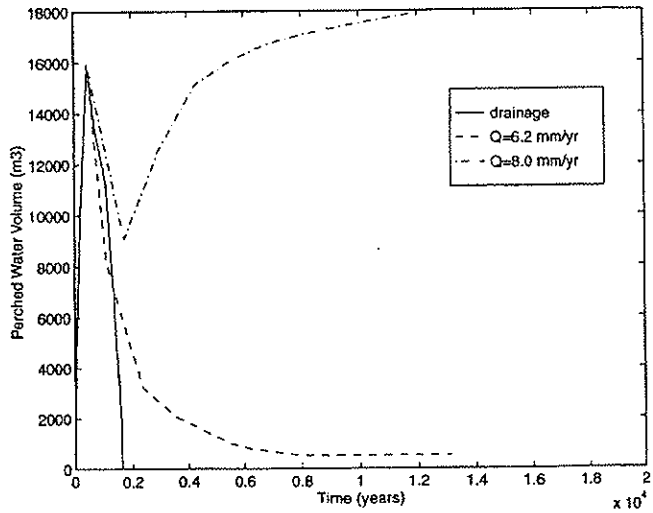


Figure 12. Temporal evolution of perched water volume for draining and $q = 6.2$ and 8.0 mm/yr simulations. Mean TSPA-93 hydrologic properties are used.

specific flux rate subsequent to the draining simulation was the point of maximum perched volume attained during draining. In the LHS-generated realization, however, due to the high initial saturations, two different points further along in the draining simulation were chosen, with an initial volume of 2,530 and 723 m^3, respectively. The results were quite similar (within 2 to 3%) in the final volume of perched water that was calculated in each simulation. The volume of perched water for each simulation reached a final value of approximately 100 m^3 by the end of the simulation.

Several simulations with different flux rates were run for the LHS-generated random realization, to determine which would produce a sustained perched volume of near the target volume

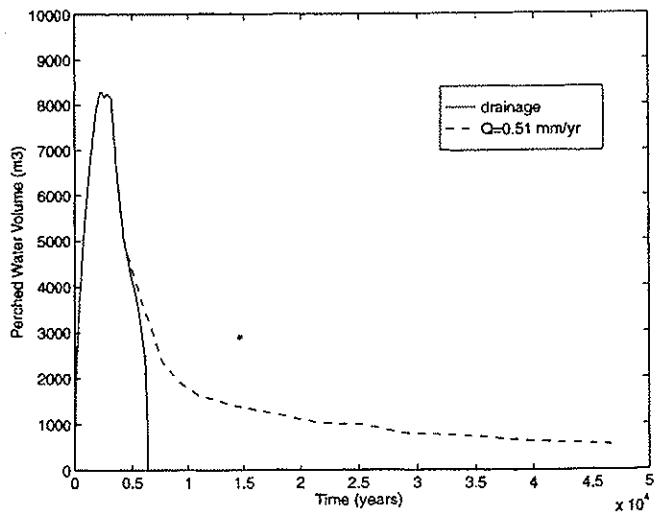


Figure 13. Temporal evolution of perched water volume for draining and $q = 0.51$ mm/yr simulations. Entropy-fit mean TSPA-93 hydrologic properties are used.

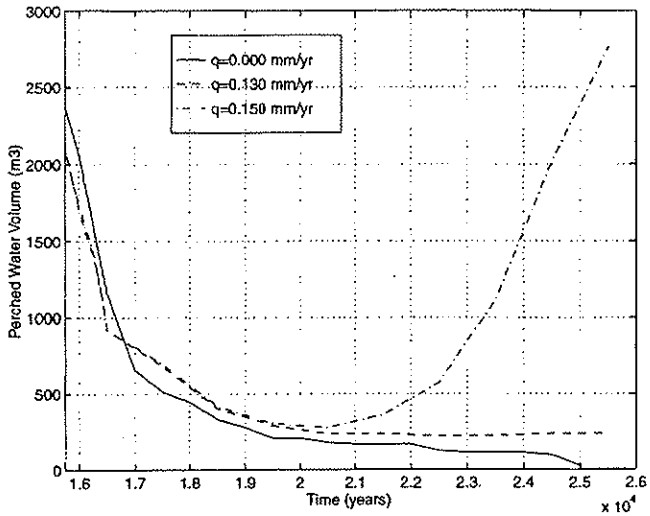


Figure 14. Temporal evolution of perched water volume for draining and $q = 0.13$ and 0.15 mm/yr simulations. LHS-generated hydrologic properties are used.

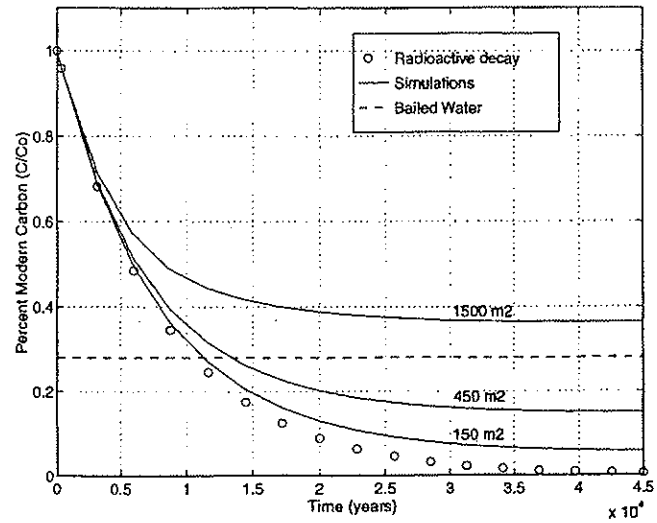


Figure 16. Depletion of perched water ^{14}C as a function of time for $q = 0.51$ mm/yr and three areal extent values. Entropy-fit mean TSPA-93 hydrologic properties are used.

of 400 to 500 m^3. However, for this realization the volumes of perched water did not decrease monotonically to a steady-state value, as was the case for the two previous realizations analyzed (Figure 14). The volume fluctuated with time but with an overall decreasing trend. Fluxes of 0.14 mm/yr and less all produced volumes that fluctuated around values smaller than the target value of 400 m^3 (volume fluctuated from 55 m^3 to about 360 m^3). This made it difficult to determine a specific volume at which it remained for a significant period of time. For the two fluxes greater than 0.14 that were tested, namely 0.15 and 0.20 mm/yr, there was a definite increasing trend in the magnitude of the volume. For this reason these fluxes were considered to not produce a sustained perched volume near the target volume. Although flux rates of 0.12 and 0.13 mm/yr produced volumes less than the target volume, the simulation with 0.13 mm/yr was the largest flux that did not show a strong tendency to increase in value near the end of the simulation. Therefore, this flux rate was chosen for subsequent geochemical analyses (Figure 14).

Equation (12), of the first part of the paper, was solved numerically for each of the three realizations, with input of the $V(t)$ behavior as inferred from the detailed flow simulations. Since the actual areal extent, A, of the perched water body is unknown, simulations have been conducted by varying this parameter. Figures 15, 16, and 17 depict the ^{14}C depletion as a

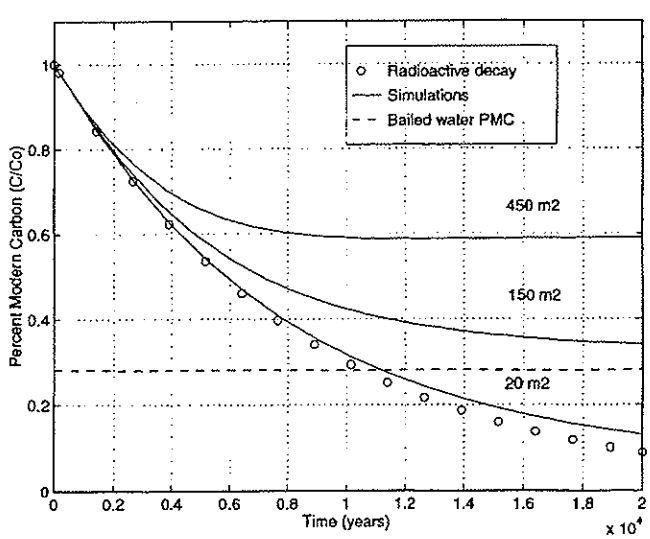


Figure 15. Depletion of perched water ^{14}C as a function of time for $q = 6.2$ mm/yr and three areal extent values. Mean TSPA-93 hydrologic properties are used.

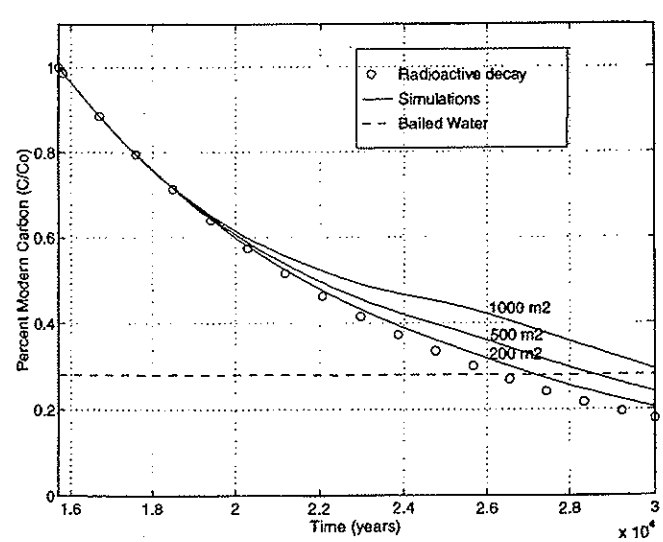


Figure 17. Depletion of perched water ^{14}C as a function of time for $q = 0.13$ mm/yr and three areal extent values. LHS-generated hydrologic properties are used.

function of time for each material property realization and also for a set of three values for the areal extent parameter A. Also shown in Figures 15, 16, and 17 is the reference simulation, which corresponds to pure radioactive decay, and the target value of $PMC_{pres} = 0.28$. Several observations can be made from these figures. First, the $q = 6.2$ mm/yr simulation, using mean TSPA-93 values, could reach the target PMC_{pres} after a residence time between 10,000 and 20,000 years for realistic areal extent values (Figure 15). This timeframe is consistent with the time required for the volume to reach a $dV/dt = 0$ and also with the change of the climate around 18 to 20 kaBP (last pluvial). On the basis of the ^{14}C analysis alone, the $q = 0.51$ mm/yr simulation, using the entropy-fit mean TSPA-93 values, seems to be plausible, since it can reach the target PMC_{pres} for realistic areal extent values, that is, before 20,000 years (Figure 16). However, the hydrological constraints are violated for this simulation since the perched water volume is consistently much larger than the target volume, V_{pres}, during this timeframe and also because $dV/dt \neq 0$, indicating nonattainment of steady-state conditions. Finally, the $q = 0.13$ mm/yr simulation, using the LHS-generated random realization properties, appears to be violating both hydrological and geochemical constraints, since (1) it attains a $dV/dt = 0$ and $V = V_{pres}$ after 25,000 years, and (2) it reaches the target PMC_{pres} after at least 30,000 years (Figure 17).

Conclusions

The major conclusions of this study are:

1. a fault-induced perched water trap model, postulated in the first part of this two-part paper (Bagtzoglou, 2002), has been proven plausible based on a fair correlation between areas of high potential recharge, location of significant structural features (e.g., faults), and known occurrences of perched water at YM;
2. a sustainable perched water body can be attained with an average deep recharge rate of 0.13, 0.51, and 6.2 mm/yr depending on the hydrologic properties of the rock units involved in the analyses;
3. only one of the three realizations tested (the one corresponding to recharge of 6.2 mm/yr) was able to satisfy both hydrological and geochemical constraints, given several key assumptions. This is in excellent agreement with the works of Stothoff et al. (1995), Stothoff (1997), and Bodvarsson et al. (1999), who predicted net infiltration rates in the range of 3 to 35 mm/yr with an average of 14 mm/yr, and 2 to 20 mm/yr with an average of 5 mm/yr, respectively. Very recently, Buscheck et al. (2002) have provided an estimate of 6 mm/yr for the average infiltration rate. This clearly demonstrates the reasonable discriminatory power of the proposed approach, which can readily be applied to any other site; and
4. it appears that for the realization that satisfies both hydrological and geochemical constraints, a present-day perched water body that consists of a combination of some minimal relict (past pluvial) water and young water from infiltration is an appropriate hypothesis. This is also in excellent agreement with observed data and the current conceptual model of flow and transport at YM (Wu et al., 1999).

Acknowledgements

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References

Bagtzoglou, A. C. 2003. Perched water bodies in arid environments and their role as hydrologic constraints for recharge rate estimation: A modeling methodology. *Environmental Forensics* 4(1):39–46.

Bish, D. L., and Aronson, J. L. 1993. Paleogeothermal and paleohydrologic conditions in silicic tuff from Yucca Mountain, Nevada. *Clays and Clay Minerals* 41:148–161.

Bish, D. L., and Chipera, S. J. 1989. *Revised Mineralogic Summary of Yucca Mountain, Nevada.* LA-11497-MS. Los Alamos, NM: Los Alamos National Laboratory.

Bodvarsson, G. S., Boyle, W., Patterson, R., and Williams, D. 1999. Overview of scientific investigations at Yucca Mountain—the potential repository for high-level nuclear waste. *Journal of Contaminant Hydrology* 38:3–24.

Broxton, D. E., Chipera, S. J., Byers, F. M., Jr., and Rautman, C. A. 1993. *Geologic Evaluation of Six Nonwelded Tuff Sites in the Vicinity of Yucca Mountain, Nevada for a Surface-Based Test Facility for the Yucca Mountain Project.* LA-12542-MS UC-814. Los Alamos, NM: Los Alamos National Laboratory.

Burger, P., and Scofield, K. 1994. Perched water at Yucca Mountain and their implications on the Exploratory Studies Facility. *EOS, Transactions, American Geophysical Union.* 75(44):250.

Buscheck, T. A., Rosenberg, N. D., Gansemer, J., and Sun, Y. 2002. Thermohydrologic behavior at an underground nuclear waste repository. *Water Resources Research* 38(3):10-1–10-19.

Byers, F. M., Jr., Carr, W. J., and Orkild, P. P. 1989. Volcanic Centers of Southwestern Nevada: Evolution of Understanding, 1960–1988. *Journal of Geophysics Research* 94(B5):5908–5924.

Craig, R. W., and Reed, R. L. 1991. *Geohydrology of Rocks Penetrated by Test Well USW H-6, Yucca Mountain, Nye County, Nevada.* USGS Water-Resources Investigations Report 89–4025. Denver, CO: US Geological Survey.

Czarnecki, J. B. 1985. *Simulated Effects of Increased Recharge on the Ground-Water Flow System of Yucca Mountain and Vicinity,*

Nevada-California. USGS Water-Resources Investigations Report 84-4344. Denver, CO: US Geological Survey.

Dohrenwend, J. C. 1987. *Basin and Range*. In *Geomorphic Systems of North America: Boulder, Colorado*, edited by W. L. Graf. Geological Society of America. Centennial Special Volume 2.

Fabryka-Martin, J. T., Dixon, P. R., Levy, S., Liu, B., Turin, H. J., and Wolfsberg, A. V. 1996. *Systematic Sampling for Chlorine-36 in the Exploratory Studies Facility*. LA-CST-TIP-96-001. Los Alamos, NM: Los Alamos National Laboratory.

Fiero, B. 1986. *Geology of the Great Basin*. Reno, NV: University of Nevada Press.

Flint, L. E., and Flint, A. L. 1990. *Preliminary Permeability and Water-Retention Data for Nonwelded and Bedded Tuff Samples, Yucca Mountain Area, Nye County, Nevada*. US Geological Survey Open-File Report 90-569. Denver, CO: US Geological Survey.

Flint, A. L., and Flint, L. E. 1994. Spatial distribution of potential near surface moisture flux at Yucca Mountain. *Proceedings of the Fifth Annual International Conference on High Level Radioactive Waste Management*. La Grange Park, IL: American Nuclear Society. pp. 2352–2358.

Flint, L. E., Flint, A. L., Moyer, T. C., and Geslin, J. K. 1995. Lateral Diversion of Water in the Paintbrush Tuff Nonwelded Hydrologic Unit, Yucca Mountain, Nevada. *EOS, Transactions, American Geophysical Union*. 76(46):F182.

Frizzell, V. A., Jr., and Shulters, J. 1990. *Geologic Map of the Nevada Test Site, Southern Nevada. 1:100,000*. US Geological Survey Miscellaneous Investigations Series Map 1-2046.

Freeze, A. R., and Cherry, J. A. 1979. *Groundwater*. Englewood Cliffs, NJ: Prentice-Hall.

Geyh, M. A., Froehlich, E., and Verhagen, B. Th. 1995. Isotope hydrogeology and water balance assessment near the Nile in Sudan. *Application of Tracers in Arid Zone Hydrology* 232:57–66.

Hevesi, J. A., Istok, J. D., and Flint, A. L. 1992a. Precipitation estimation in mountainous terrain using multivariate geostatistics. Part I: Structural analysis. *Journal of Applied Meteorology* 31(7):661–676.

Hevesi, J. A., Flint, A. L., and Istok, J. D. 1992b. Precipitation estimation in mountainous terrain using multivariate geostatistics. Part II: Isohyetal Maps. *Journal of Applied Meteorology* 31(7):677–688.

Hevesi, J. A., Ambos, D. S., and Flint, A. L. 1994. A preliminary characterization of the spatial variability of precipitation at Yucca Mountain, Nevada. *Proceedings of the Fifth International High Level Radioactive Waste Management Conference*. La Grange Park, IL: American Nuclear Society. pp. 2520–2529.

Iman, R. L., and Shortencarier, M. J. 1984. *A FORTRAN 77 Program and User's Guide for the Generation of Latin Hypercube and Random Samples for Use with Computer Models*. Albuquerque, NM: Sandia National Laboratories.

Istok, J. D., Rautman, C. A., Flint, L. E., and Flint, A. L. 1994. Spatial variability in hydrologic properties of a volcanic tuff. *Ground Water* 32(5):751–760.

Loscot, C. L., and Hammermeister, D. P. 1992. *Geohydrologic Data from Test Holes UE-25 UZ#4 and UE-25 UZ#5, Yucca Mountain Area, Nye County, Nevada*. USGS Open-File Report 90-369. Denver, CO: US Geological Survey.

National Climatic Data Center. (1994) *WBAN Hourly Surface Observations*. March 1984 through February 1994. Asheville, NC: National Oceanic and Atmospheric Administration.

Ofoegbu, G. I., Bagtzoglou, A. C., Green, R. T., and Muller, M. 1999. Effects of perched water on thermally driven moisture flow at the proposed Yucca Mountain repository for high-level waste. *Nuclear Technology* 125(2):235–253.

Ofoegbu, G. I., Painter, S., Chen, R., Fedors, R. W., and Ferrill, D. A. 2001. Geomechanical and thermal effects on moisture flow at the proposed Yucca Mountain nuclear waste repository. *Nuclear Technology* 134(3):241–262.

Quade, J., and Mifflin, M. 1995. Fossil spring deposits in the southern Great Basin and their implications for changes in water-table levels near Yucca Mountain, Nevada, during Quaternary time. *Geological Society of America Bulletin* 107(2):213–230.

Russell, C., Hess, J., and Tyler, S. 1987. Hydrogeologic investigations of flow in fractured tuffs, Rainier Mesa, Nevada Test Site. *Flow and Transport Through Unsaturated Fractured Rock*, edited by D. D. Evans and T. J. Nicholson. Geophysical Monograph 42. Washington, DC: American Geophysical Union. pp. 43–50.

Scott, R. B., and Bonk, J. 1984. *Preliminary Geologic Map (1:12,000 scale) of Yucca Mountain, Nye County, Nevada, with Geologic Cross Sections*. USGS Open-File Report 84-494. Denver, CO: US Geological Survey.

Spaulding, W. G. 1985. *Vegetation and Climates of the Last 45,000 Years in the Vicinity of the Nevada Test Site, South-Central Nevada*. US Geological Survey Professional Paper 1329. Washington, DC: US Government Printing Office.

Stewart, J. H. 1984. Basin-Range Structure in Western North America: A Review. *Cenozoic Tectonics and Regional Geophysics of the Western Cordillera*. Memoir 152. Boulder, CO: The Geophysical Society of America.

Stirewalt, G., Henderson, B., and Young, S. 1994. *A Preliminary Three-Dimensional Geological Framework Model for Yucca Mountain, Nevada: Report to Accompany Model Transfer to the Nuclear Regulatory Commission*. CNWRA 94-023. San Antonio, TX: Center for Nuclear Regulatory Analyses.

Stirewalt, G. L., and Henderson, D. B. 1995. A preliminary three-dimensional geological framework model for Yucca Mountain. *Proceedings of the Sixth International Conference on High Level Radioactive Waste Management*. La Grange Park, IL: American Nuclear Society. pp. 116–118.

Stothoff, S. 1995. *BREATH Version 1.1-Coupled Flow and Energy Transport in Porous Media: Simulator Description and User Guide*. NUREG-CR 6333. Washington, DC: Nuclear Regulatory Commission.

Stothoff, S. A. 1997. Sensitivity of long-term bare soil infiltration simulations to hydraulic properties in an arid environment. *Water Resources Research* 33(4):547–558.

Stothoff, S. A., Bagtzoglou, A. C., and Castellaw, H. M. 1995. Estimation of spatial distribution of recharge factors at Yucca Mountain. In *NRC High-Level Radioactive Waste Research at CNWRA: January-June 1995*, edited B. Sagar. CNWRA 95-01S. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses. pp. 9-5–9-12.

Thordarson, W. 1965. *Perched Ground Water in Zeolitized-Bedded Tuff, Rainier Mesa and Vicinity, Nevada Test Site, Nevada*. US Geological Survey Open-File Report TEI-862.

US Department of Energy (DOE). 1986. *Final Environmental Assessment: Yucca Mountain Site, Nevada Research and Development Area, Nevada*. DOE/RW-0073. Washington, DC: US Department of Energy.

US Department of Energy (DOE). 1988. *Site Characterization Plan, Yucca Mountain Site, Nevada Research and Development Area, Nevada*. DOE/RW-0199. Washington, DC: US Department of Energy.

US Department of Energy (DOE). 1992. *Report of Early Site Suitability Evaluation of the Potential Repository Site at Yucca Mountain, Nevada*. Washington, DC: US Department of Energy.

Wang, J. S. Y., Cook, N. G. W., Wollenberg, H. A., Carnahan, C. L., Javandel, I., and Tsang, C. F. 1993. Geohydrologic data and models of Rainier Mesa and their implications to Yucca Mountain. *Proceedings of the Fourth International Conference on High Level Radioactive Waste Management*. La Grange Park, IL: American Nuclear Society. pp. 675–680.

Whitfield, M. S., Cope, C. M., and Loscot, C. L. 1993. *Borehole and Geohydrologic Data for Test Hole USW UZ-6, Yucca Mountain Area, Nye County, Nevada*. USGS Open-File Report 92-28. Denver, CO: US Geological Survey.

Wilson, M. L., Gauthier, J. H., Barnard, R. W., Barr, G. E., Dockery, H. A., Dunn, E., Eaton, R. R., Guerin, D. C., Lu, N., Martinez, M. J., Nilson, R., Rautman, C. A., Robey, T. H., Ross, B., Ryder, E. E., Schenker, A. R., Shannon, S. A., Skinner, L. H., Halsey, W. G., Gansemer, J. D., Lewis, L. C., Lamont, A. D., Triay, I. R., Meijer, A., and Morris, D. E. 1994. *Total-System Performance Assessment for Yucca Mountain—SNL Second Iteration (TSPA-1993)*. SAND93-2675. Albuquerque, NM: Sandia National Laboratories.

Wood, W. W., and Sanford, W. E. 1995. Chemical and isotopic methods for quantifying groundwater recharge in a regional, semiarid environment. *Ground Water* 33(3):458–468.

Wu, Y. S., Ritcey, A. C., and Bodvarsson, G. S. 1999. A modeling study of perched water phenomena in the unsaturated zone at Yucca Mountain. *Journal of Contaminant Hydrology* 38:157–184.

Yang, I. C., Rattray, G. W., and Yu, P. 1996. *Interpretations of Chemical and Isotopic Data from Boreholes in the Unsaturated Zone at Yucca Mountain, Nevada.* US Geological Survey Water-Resources Investigations Report 96-4058.

Young, S. R., Stirewalt, G. L., and Morris, A. P. 1992. *Geometric Models of Faulting at Yucca Mountain.* CNWRA 92-008. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses.

ENCLOSURE

#6

SECTION 7

WATER RESOURCES RESEARCH, VOL. 38, NO. 3, 10.1029/2000WR000010, 2002

Thermohydrologic behavior at an underground nuclear waste repository

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[1] We present a multiscale model that simulates coupled thermal and hydrological behavior driven by radioactive decay heat from a potential nuclear waste repository at Yucca Mountain, Nevada. We use this model to evaluate repository performance for different designs with respect to major thermal design goals (e.g., keeping waste packages dry). A locally boiling or globally boiling design uses rock dry out to create dry (low relative humidity (RH)) conditions around waste packages for a long period of time. A subboiling design eliminates boiling in the host rock (possibly reducing uncertainty) but is less effective at maintaining dry conditions. The addition of backfill increases the duration of RH reduction significantly without added boiling in the host rock but at the cost of higher waste package temperatures. The interaction between engineering design variables and natural system factors that affect thermohydrologic behavior is highly nonlinear. As a consequence, designs that differ by seemingly small details can result in markedly different thermohydrologic behavior and consequently repository performance, whereas with regards to other details, large differences may have little or no effect. *INDEX TERMS:* 1829 Hydrology: Groundwater hydrology; 1832 Hydrology: Groundwater transport; 1875 Hydrology: Unsaturated zone; 1878 Hydrology: Water/energy interactions; *KEYWORDS:* Yucca Mountain, thermal, hydrological, repository, multiscale

1. Introduction

[2] Yucca Mountain, located 145 km northwest of Las Vegas, Nevada, on federally owned land on the edge of the U.S. Department of Energy's Nevada Test Site, has been studied intensively for more than 15 years. It is being considered as a potential site for the nation's first geologic repository for high-level nuclear waste. If the site is licensed, cylindrical waste packages containing nuclear waste will eventually be placed in ~50 horizontal tunnels, ~5.5 m in diameter and 1 km in length, several hundred meters below the ground surface in partially saturated volcanic tuff. Radioactive decay of this nuclear waste will produce an initial heat flux many times larger than the heat flux in some natural geothermal systems. This heat flux will change the thermal and hydrologic environment at Yucca Mountain significantly, affecting both the host rock and conditions within the tunnels (called emplacement drifts).

[3] We need to understand the interaction of the natural system with the emplaced wastes in order to design a repository that isolates the waste from the biosphere; one major concern is the protection of groundwater from radionuclide contamination. Numerical models of this coupled system, backed by sound field and laboratory data, are necessary because of licensing requirements for performance assessments at least 10,000 years into the future, as well as for extensive "what if" design evaluation.

[4] In this paper, we present a multiscale modeling approach that effectively simulates three-dimensional (3-D) discrete heat source, mountain-scale, thermohydrologic behavior at Yucca Mountain and report on the results of a modeling study based on this approach. Our aims are to (1) describe the relationship between repository design, the natural system, and thermohydrologic behavior, (2) provide insights regarding thermal management strategies for an underground nuclear waste repository, and (3) demonstrate the power of this multiscale modeling approach as a performance assessment and engineering design tool for complex thermohydrologic problems. This approach differs from previous modeling studies that have focused on either mountain-scale behavior with a smeared heat source or local behavior near individual emplacement drifts without consideration of mountain-scale heat flow [e.g., *Haukwa et al.*, 1999; *Pruess et al.*, 1990a, 1990b; *Buscheck and Nitao*, 1993; *Buscheck et al.*, 1995, 1996].

2. Yucca Mountain Thermohydrology

2.1. Ambient Hydrological System

[5] Yucca Mountain is composed of a sequence of tuffs deposited as ash flow sheets about 13 million years ago. Some units are completely devitrified and welded, while others are vitric or partially vitric with various degrees of welding. Some are also zeolitized to varying degrees. In general, the more welded units are more densely fractured. Hydrostratigraphic units at Yucca Mountain have been defined primarily based on degree of welding [*Montazar and Wilson*, 1984]. From the ground surface to the water table these units are generally referred to as Tiva Canyon welded (TCw), Paintbrush nonwelded (PTn), Topopah Spring welded (TSw), Calico Hills nonwelded (CHn) and Crater Flat, which is broken down into Prow Pass (pp), and Bullfrog (bf).

[6] Most of the total fluid storage capacity of the welded units at Yucca Mountain is contained in the matrix pores. The permeability in the rock matrix in these units, however, is very low and therefore fractures are the primary conduits for large-scale flow of water, air, and water vapor in these units. In some of the nonwelded units, fracturing is much less extensive, and the rock matrix is more permeable than in the welded units, causing gas-

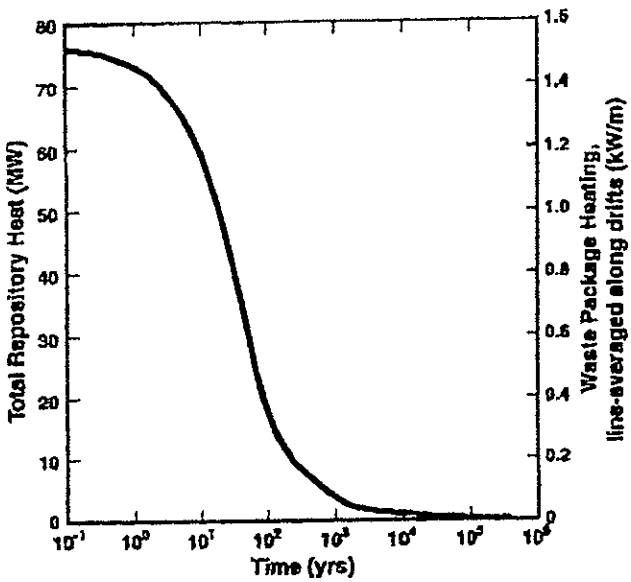

Figure 1. Repository heat output as a function of time for the design currently being evaluated for a Yucca Mountain nuclear waste repository. Note that the total repository heat divided by the average heat output per length of drift is equal to the total length of drift in the repository, ~50 km. These values do not account for the effects of ventilation.

[7] The climate at Yucca Mountain is arid to semiarid, with infiltration from rainfall and snowmelt. Field data to date suggest that water that infiltrates at the ground surface percolates more-or-less vertically downward to the water table 700 m beneath the surface, with some degree of lateral diversion and the occasional occurrence of perched or semiperched aquifers [see *Flint et al.*, 2001]. A recent site-scale model for ambient unsaturated zone hydrology at Yucca Mountain is presented by *Wu et al.* [1999]. Note that under ambient conditions the relative humidity (RH) in the unsaturated zone at the elevation of the repository is very high (RH > 99%).

2.2. Adding Radioactive Decay Heat

[8] The potential repository is located in the vadose zone in the TSw hydrostratigraphic unit along a nearly horizontal plane, approximately midway between the ground surface and the water table. The repository is expected to accommodate the emplacement of spent nuclear fuel from commercial nuclear power plants and solidified high-level waste produced during the reprocessing of spent nuclear fuel and may also include minor amounts of other radioactive material. Heat output declines exponentially with time, continuing for tens of thousands of years because of the very long half-life of many of the radionuclides (Figure 1).

[9] After the emplacement of heat-generating nuclear waste the thermally driven flow of water vapor away from the heat source causes a redistribution of the pore fluids within a potentially large volume of rock. Depending on the thermal design of the repository, this volume can extend from the ground surface to some distance below the water table and over an area larger than the repository footprint. Water in the matrix pores evaporates, creating zones of drifts to where cooler temperatures cause it to condense, forming condensation zones outside of the dry out zones. The reduction in liquid-phase saturation causes a reduction in relative humidity at both the near-field host rock as well as in the emplacement drifts. Heat pipes can result from the countercurrent flow of water vapor and liquid water between the dry out and condensation zones. The magnitude of the liquid flux in this heat pipe can greatly exceed the magnitude of ambient liquid-phase fluxes. As the heat pulse decays, the system gradually rewets, returning to ambient (humid) preheating conditions.

2.3. Thermohydrologic Behavior in Host Rock

[10] In the host rock, local thermohydrologic behavior is dominated by whether a location is inside or outside of the zone of boiling temperatures, 96°C at the elevation of the potential repository horizon at Yucca Mountain ~1100 m above mean sea level. Although evaporation and condensation occur at below-boiling temperatures, the thermally driven vapor fluxes in the repository horizon are generally not great enough to result in significant dry out (and relative humidity reduction) in the rock unless temperatures are well above the boiling point.

[11] The boiling zone evolves with time. After waste emplacement a small zone of boiling-to-above-boiling temperatures forms in the volume immediately encircling each individual emplacement drift. For a "globally boiling" design these boiling zones grow and coalesce. As thermal output wanes, the boiling zones shrink, and the boiling zone in the host rock eventually dissipates completely. In "locally boiling" designs, these zones never coalesce; the boiling zones around each drift always remain distinct and separate. According to our definition a "subboiling" repository creates no boiling in the host rock; however, boiling may occur in the drifts.

[12] Whether or not the boiling zones around individual drifts coalesce is important because globally boiling conditions promote the development of a thick condensate zone above the repository. Note that this condensate zone will also include the percolation of ambient water that is unable to drain through or around the repository (because it is blocked by the coalesced boiling zone) and on down to the water table. The thickness of this condensate zone may reach tens of meters or more. A thick condensate zone may result in unstable and/or focused condensate drainage into relatively cooler regions of the repository, possibly resulting in seepage into emplacement drifts. A thick condensate zone will also result in somewhat greater liquid flux above the repository horizon during the postboiling rewetting period and, more generally, increases uncertainty with respect to infiltration flow paths above the repository. If the thermal design does not result in coalescence of boiling zones, condensate will be able to drain continuously between the drifts. Variation in the spatial extent and duration of the boiling zone along the drift axis is also important. Nonuniformity in boiling conditions along the drift axis (resulting from waste-package-to-waste-package variability in heat output) makes it more likely for seepage and/or condensate to be focused onto cooler waste packages.

2.4. Thermohydrologic Behavior in Repository Drifts

[13] The most recent repository design includes 1.67-m-diameter waste packages constructed of corrosion-resistant materials, which are overlain by upside down, U-shaped, corrosion-resist-

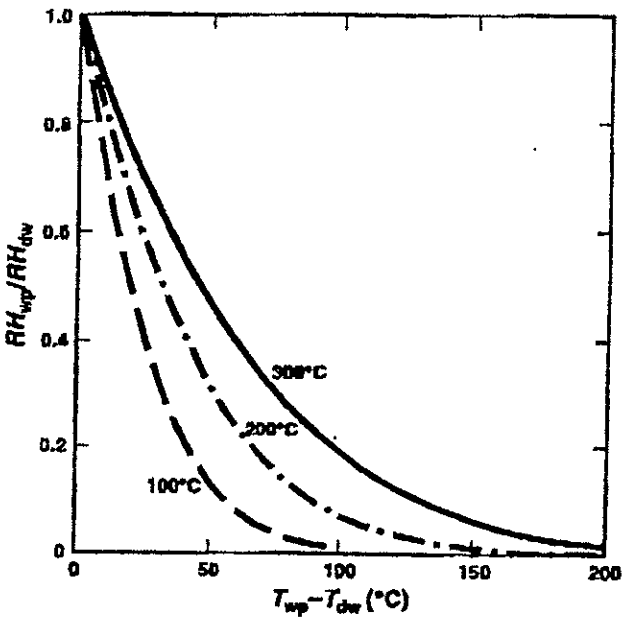

Figure 2. Ratio of relative humidity on the waste package surface to relative humidity on the drift wall surface versus the temperature difference between these surfaces for three different temperatures (taken to be the average of the drift wall and waste package temperatures).

granular backfill such as sand emplaced between the drift wall and drip shield has also been considered as a design alternative [*Civilian Radioactive Waste Management System* (*CRWMS*), 1999b].

[14] Two important factors influence the thermohydrologic conditions within the emplacement drift. The first is whether or not temperatures at the drift wall are above the boiling point, which affects whether the relative humidity in the near-field host rock is reduced relative to ambient (humid) conditions as well as the likelihood of water seeping into the drift. The second is the temperature difference between the waste package and drift wall, which strongly affects how much lower the relative humidity is on the waste package than on the drift wall (Figure 2). Note that the ratio of relative humidity on the waste package to relative humidity on the drift wall for a given temperature difference between these two surfaces decreases as the absolute temperature on the waste package decreases. Backfill placed between the drift wall and the waste package is one way to create a significant temperature difference between the two surfaces.

3. Thermal Management

3.1. Thermal Design Variables

[15] There are many thermal design variables that affect thermohydrologic behavior in an underground nuclear waste repository (Table 1). These design variables include the average areal heat generation density of the waste inventory over the heated repository footprint and the average lineal heat generation density along the drifts. For a given waste inventory these two variables constrain both the distance between drifts and the size of the required repository footprint. One way to reduce the heat generation density is to age the waste in surface storage, because older spent fuel has a lower thermal power output than younger spent fuel. Forced natural) ventilation of the emplacement drifts also reduces the effective heat output of the emplaced waste.

[16] Other engineering variables include the placement of the repository horizon relative to the ground surface and the local hydrostratigraphy. The depth of the repository horizon below the ground surface translates to the thickness of insulting rock between the repository and the ground surface, which is a constant-temperature boundary that acts like a heat sink. In-drift configuration, including most notably the presence or absence of backfill in the emplacement drifts, and the properties of any in-drift materials are also important.

[17] Waste package spacing affects the degree of nonuniformity of heating conditions along the axis of the drift. Individual waste packages are cylindrical in shape and 3–6 m long. If waste packages are spaced far apart from each other along the drift ("point load" waste package spacing), heating conditions along the drift will be much less uniform. If the waste packages are spaced nearly end to end ("line load" waste package spacing), the line of waste packages will share their heat output more effectively and will therefore act like a uniform line source of heat. Line waste package spacing results in more intense, localized, and persistent rock dry out around the drifts and more efficient condensate shedding between the drifts than does point load waste package spacing with the same overall areal heat generation density. Point load waste package spacing results in less intense rock dry out around the drifts and less uniform thermohydrologic conditions along the drifts [*Buscheck et al.*, 1998]. Fuel blending

Table 1. Key Thermal Design Variables and Natural System Factors Influencing Thermohydrologic Behavior

Engineering Design Variables	Natural System Factors
Overall areal heat generation density of waste inventory	infiltration rate
Average heat generation density along drifts	thermohydrologic properties: thermal conductivity, matrix imbibition, and capillarity wicking into [illegible]
Distance between drifts	overburden thickness
Age of the nuclear waste at emplacement	thermal boundary conditions (T and RH) at ground surface
Location of repository horizon	
Repository footprint	
Waste package spacing (line load versus point load)	
Waste package sequencing	

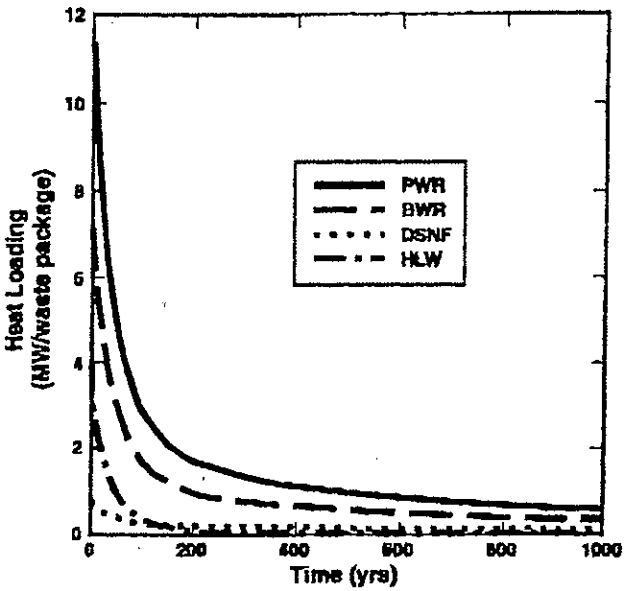

Figure 3. Comparison of thermal output for four major waste packages as a function of time. The two civilian spent nuclear fuel packages, from power water reactors (PWR) and from boiling-water reactors (BWR), have much greater thermal output than the defense spent nuclear fuel (DSNF) and high-level waste (HLW) packages. Each waste package contains multiple waste assemblies (e.g., a PWR waste package contains 21 PWR assemblies).

(i.e., the mixing and matching of spent-fuel assemblies of different thermal power in a given waste package as well as the mixing and matching of waste packages of different thermal power along emplacement drifts) can be utilized to help reduce the nonuniformity of thermohydrologic conditions along drifts.

3.2. Natural System Factors

[18] Important natural system factors that affect the thermohydrologic environment include thermohydrologic properties of the repository host rock, overburden thickness above the repository, and the magnitude and spatial and temporal distribution of infiltration flux (Table 1). Of these factors, infiltration flux is the most important. Unlike the engineering design variables, there is nothing that can be done to change the natural system. We can, however, try to minimize uncertainty by learning as much as possible about the natural system and engineering the repository with natural system variation and uncertainty in mind.

3.3. Thermal Design Goals

[19] There are two categories of thermal design goals for an underground nuclear waste repository. The first category is focused on generating favorable environmental conditions in the emplacement drifts for the waste packages. These goals include (1) keeping temperatures below critical temperatures for engineered materials, (2) limiting water seeping into drift (i.e., delaying the onset of potential seepage, and (3) keeping waste packages dry (i.e., low relative humidity) until cool. The second category of goals focuses on reducing uncertainty in predicted repository performance. These goals include (1) limiting the extent of boiling conditions in host rock and (2) promoting uniform heating conditions along emplacement drifts.

[20] We address the waste package environment goals first. The first goal is limiting the temperature-dependent degradation of key in-drift components, such as the cladding of the spent nuclear-fuel rods in the waste packages. Critical temperatures for the engineered materials are material-dependent but in general, upward of 300°C. The second goal is to limit water seeping into the drifts, which reduces the likelihood of seepage onto the waste packages. Preventing liquid water from contacting the waste packages is important to reduce corrosion potential and limit the potential for radionuclide release and transport in the event that waste packages are breached. Seepage potential is very difficult to assess because of the role of small-scale heterogeneity and our limitations in modeling such processes, but, in general, seepage into repository drifts is less likely to occur while above-boiling conditions exist at the drift wall.

[21] The third goal is to keep the waste packages dry (i.e., low relative humidity) until cool. This goal concerns limiting degradational mechanisms that are enhanced with the presence of liquid films at elevated temperatures. It relates to the possibility of the formation of brines at temperature above 100°C through water absorption by hygroscopic salts that may exist on component surfaces after extensive boiling has occurred. Reducing relative humidity on waste packages is enhanced by (1) the presence of above-boiling conditions in the host rock at the drift wall boundary, (2) inclusion of in-drift components in the design which create a temperature difference between drift wall and waste package (Figure 3), and (3) the absence of seepage into the drift.

[22] Reducing uncertainty in predicting repository performance has been interpreted by many to mean primarily limiting the extent of boiling in the host rock. The premise is that complexity, and therefore uncertainty, can be reduced by avoiding processes and conditions associated with boiling conditions. The main concern is coupled thermohydrolic-chemical-mechanical behavior. Possible changes in material properties due to heating include some which may be temporary (e.g., fracture closure due to thermal-mechanical stresses) and others which may be permanent (e.g., mineral

Table 2. Summary of Repository Designs Considered in This Study[A]

Design	Backfill	Thermal Management Concept	Initial Thermal Loading, MW m^{-2}	Preclosure Ventilation, Years
1	yes	subboiling	18	200
2	no	subboiling	18	200
3	yes	locally boiling	18	50
4	no	locally boiling	18	50
5	yes	globally boiling	27	50
6	no	globally boiling	27	50

alteration in fractures from thermochemical processes). Significant thermohydrologic-chemical-mechanical processes (e.g., evaporation) occur below boiling temperatures, however, and it is difficult to quantify the uncertainty reduction associated with avoiding boiling conditions.

[23] Another concern with respect to reducing uncertainty is that flow paths might lead to focused flow onto specific waste packages. Natural heterogeneity in rock permeability and porosity cannot be avoided, but uncertainty in flow paths is affected by engineering design choices. For example, globally boiling conditions increase the potential for localized liquid-phase flux above the repository, creating additional uncertainty with respect to the likelihood for drift seepage. Also, flow path uncertainty is reduced by uniform heating conditions along the drift, which reduces the chances of flow focusing on cooler waste packages. Utilizing high-capillarity backfill material against the drift wall, which helps to attenuate any focused seepage that does enter drifts, can also add to uncertainty reduction. (We discuss backfill in more detail in section 5.2).

[24] These thermal design goals are interdependent, and therefore trade-offs must be made, as we illustrate in the modeling results presented in section 5. In addition, there are many other nonthermal performance considerations (e.g., backfill has been suggested as a protection against rockfall onto waste packages from the drift ceiling), as well as cost and constructability issues. In this paper, we examine the performance of several different repository designs with respect to thermal performance.

3.4. Repository Designs

[25] Fortunately, given the large number of possible combinations of engineering design variables and natural system factors, the most significant aspects of the thermohydrologic response of Yucca Mountain to thermal loading can be described, to first order, by considering only a few major attributes. These include whether boiling or subboiling conditions occur in the host rock, whether or not the boiling zones around individual drifts coalesce, the degree of nonuniformity of heating conditions along emplacement drifts, and the relative humidity difference between the drift wall and surfaces of engineered components within drifts. The repository designs considered in this paper cover much of this range.

[26] We consider six designs, including subboiling, locally boiling, and globally boiling designs, each with and without backfill in the emplacement drifts (Table 2). These six repository designs were chosen because of their relationship to the evolution of design concepts that have been considered for the potential repository at Yucca Mountain.

[27] Each of these repository designs includes a preclosure period during which the drifts are ventilated to remove 70% of the heat generated by waste packages, so only 30% of the heat generated by waste packages is available to heat the host rock during the preclosure period. Drip shields and, in some designs, backfill are emplaced at the end of the preclosure period (just prior to the start of the postclosure period). Ventilation of the emplacement drifts ceases at the end of the preclosure period, so 100% of the heat generated by waste packages is available to heat the host rock during the postclosure period. We have used fuel blending and "line load" waste package spacing for all six designs. We have assumed that all six designs share the identical repository footprint

[28] The locally boiling design has an initial heat flux of [illegible] MW km^{-2} (Figure 1) averaged over the heated repository [illegible] print, a distance between emplacement drifts centerlines of 81 m, and a 50-year preclosure period. The thermal management strategy for the locally boiling design is to generate limited host rock dry out to promote dry conditions in the emplacement drifts, while preventing the coalescence of the boiling zones. This promotes continuous drainage between drifts and limits the volume of the host rock exposed to boiling and above-[illegible] conditions. This locally boiling design without backfill is the design currently being evaluated by the Yucca Mountain Project [*Civilian Radioactive Waste Management System* (CR[illegible] 1999a].

[29] The subboiling repository designs are identical to locally boiling designs, except that the preclosure period lasts for 200 years rather than 50 years, significantly reducing the magnitude of the heat flux at the beginning of the postclosure period. (Note that the beginning of the postclosure period is when peak temperatures occur in the host rock and in the drift.) In the subboiling repository designs, host rock dry out is not part of the thermal management strategy. This strategy focuses on reducing uncertainty in the thermohydrologic behavior in the host rock, which is accomplished with the elimination of boiling conditions in the host rock, and on minimizing waste package temperatures. This strategy [illegible] that the benefits of uncertainty reduction associated with the elimination of boiling conditions in the host rock, together with minimized waste package temperatures, outweigh the benefit resulting from rock dry out and generating drier conditions in the drifts and on waste packages. Note that the four subboiling and locally boiling designs are identical for the first 50 years. The only differences are the presence or absence of backfill and the duration of ventilation.

[30] The globally boiling repository designs differ from the subboiling and locally boiling designs in that the drifts are spaced more closely together (54 m in contrast to 81 m), resulting in an initial heat flux of 27 MW km^{-2} averaged over the heated repository footprint. The preclosure period is 50 years. The thermal management strategy for a globally boiling repository places an emphasis on generating extensive host rock dry out to promote persistent dry conditions in the emplacement drifts and on waste packages. This strategy assumes that extensive and persistent rock dry out is worth the trade-off of any uncertainties that occur as a result of the extra condensate buildup above the repository caused by the coalesced boiling zones and the greater spatial and temporal extent of boiling conditions in the host rock. This globally boiling repository design is similar to the design considered previously by the Yucca Mountain Project in a recent performance assessment [*Civilian Radioactive Waste Management System* (*CRWMS*), 1998].

[31] The three engineered backfill designs are identical to the no-backfill designs except that a coarse sand backfill is emplaced along with the drip shield, just prior to the start of the postclosure period. The thermal management strategy for these designs includes generating a temperature difference between the waste packages and drift wall to further reduce relative humidity on the waste packages.

4. A Multiscale Modeling Approach

4.1. Overview

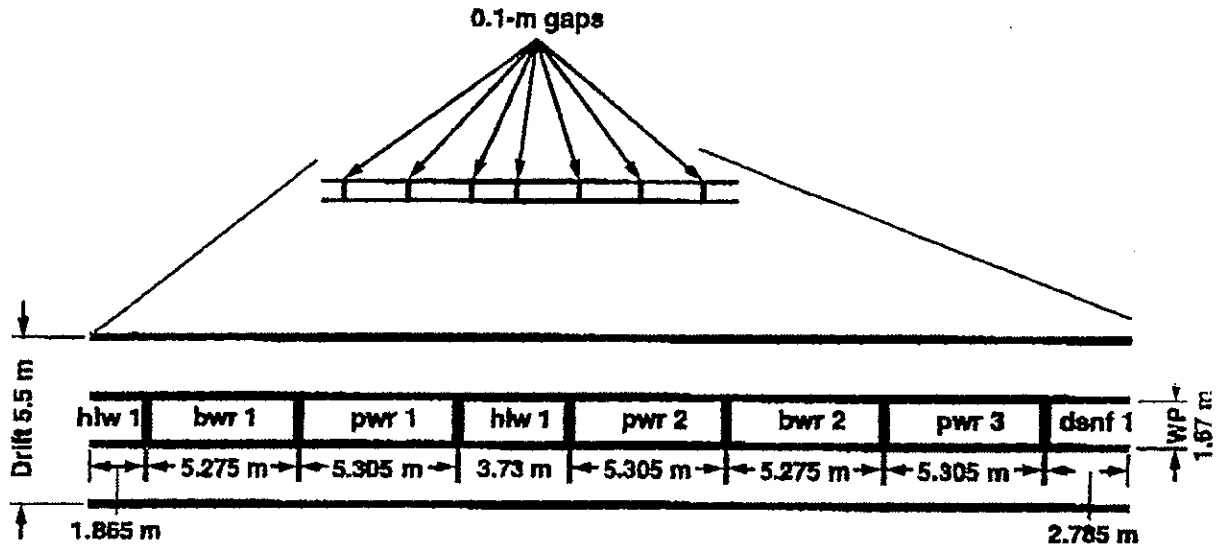

Figure 4. Waste package sequencing assumed in this study.

ng tool that simultaneously accounts for processes occurring at a scale of a few tens of centimeters around individual waste packages and emplacement drifts and also at the scale of the mountain. The reality is that a single numerical model cannot currently do this because it requires too large a computational cost to be a viable simulation tool for performance assessment and engineering design. Note that performance assessment and design analysis both require the ability to conduct a relatively large number of realizations. This multiscale modeling approach was used to model more than 20 different realizations for the Total System Performance Assessment for the Yucca Mountain Viability Assessment [*CRWMS*, 1998]. This approach has also been used to model more than 20 alternative repository designs during the license application design selection process [*CRWMS*, 1999b] and in six different realizations for the Total System Performance Assessment for the Site Recommendation [*CRWMS*, 2000a].

[33] Conceptually, our approach is simple. We directly simulate thermohydrologic behavior for an "average" waste package using a two-dimensional (2-D) drift-scale cross section for a variety of heat generation densities at numerous locations throughout the repository footprint. In these simulations we account for the flow of liquid and gas (water vapor and air) through variably saturated porous media with a dual-permeability description of permeability. We also account for two-phase behavior (i.e., evaporation, boiling, and condensation). Open drifts are modeled as porous media with very high permeability and porosity. We consider thermal conduction and convection in rock and thermal conduction, convection, and radiation in the open cavities in the emplacement drifts.

[34] We then modify these 2-D thermohydrologic model results with three-dimensional (3-D) thermal model results to account for 3-D heat flow at the mountain scale and for 3-D heat flow at the drift scale, which account for waste-package-to-waste-package variability in heat output. (Some waste packages will generate much more heat than other waste packages.) We assume that any mountain-scale movement of water and water vapor along the drift between the drifts). We also neglect any changes in rock properties due to any coupled thermohydrologic-chemical-mechanical processes and the effect of dissolved solutes on the thermohydrologic properties of water.

[35] The multiscale modeling approach considers the influence of the following variables as a function of geographic location in the repository: local stratigraphy, overburden thickness (i.e., distance between the repository and ground surface, which varies by ~150 m across the repository), thermal boundary conditions, and infiltration flux. It also considers the influence of the proximity to the edge of the repository, which is important because a waste package close to the repository edge will cool more quickly than one at the repository center. The differences in temperature arise as a result of proximity to the repository edges is assumed to be governed by thermal conduction in the rock. This assumption is equivalent to saying that convective heat transfer mechanisms (notably, buoyant gas-phase convection and the heat pipe effect) have a negligible influence on lateral mountain-scale heat flow at Yucca Mountain. This assumption tends to preserve temperature differences that arise as a result of differences in proximity to the repository edges.

[36] We represent all possible waste packages emplaced in the repository by four major types: commercial spent nuclear fuel from pressurized-water reactors (PWRs), commercial spent nuclear fuel from boiling-water reactors (BWRs), high-level waste (HLW), and defense spent nuclear fuel (DSNF). The only point that is relevant here is that the heat generation rate versus time relationships for these four waste package types are different (Figure 3). We assume that waste packages will be sequenced in such a way to minimize the heating variability along the drift (i.e., placing hot waste packages next to cold waste packages). In this paper, we consider a narrow range of possible waste package sequencing (Figure 4) that results in eight distinct local heating conditions for waste packages. For example, we distinguish between a BWR placed between a PWR and a HLW and a BWR placed between two PWRs. The differences in temperature between relatively hotter waste package locations and cooler

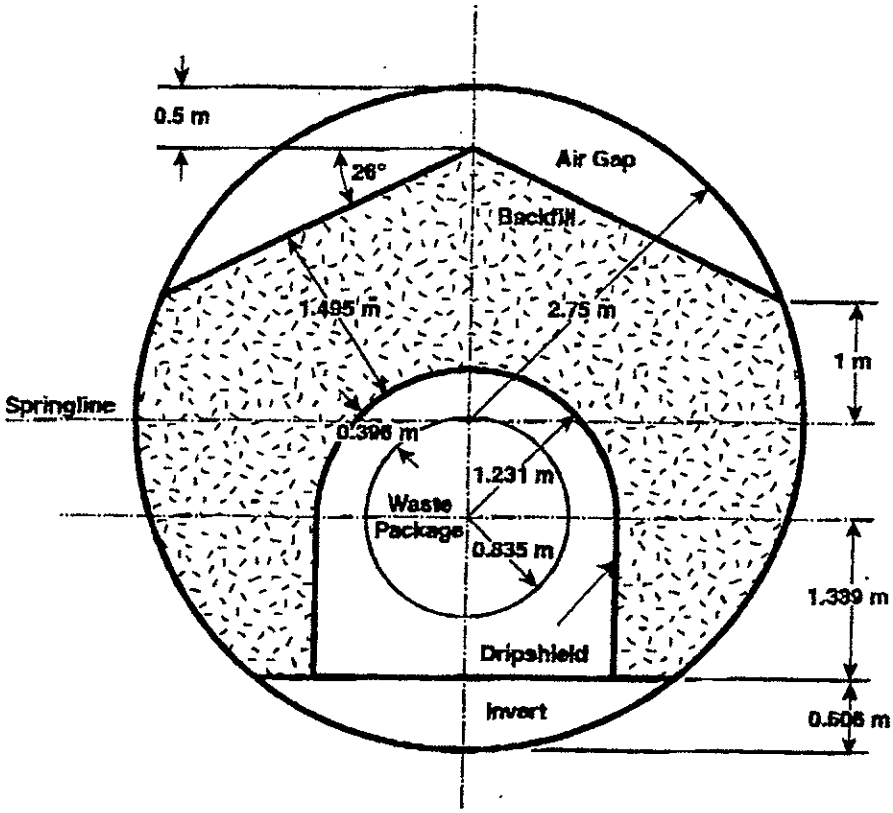

Figure 5. Geometric configuration of the engineered components inside the drifts for the cases with backfill. Figure 5 also applies to cases without backfill except that the air gap also occupies the portion of the drift indicated to be backfill.

equivalent to saying that convective heat transfer mechanisms (notably, buoyant gas-phase convection in the drift) do not significantly contribute to the attenuation of temperature variations along the axis of the drift. This assumption tends to preserve temperature variability along the drifts.

[37] To implement this multiscale approach, we have developed a modeling system [*CRWMS*, 2000a] we call the Multiscale Thermohydrologic Model (MSTHM), which we describe in section 4.4. First, we discuss the unsaturated zone hydrology model on which the natural system aspects of the MSTHM are based, and then we present the governing equations we use in all our simulations.

4.3. Unsaturated Zone Hydrology Model

[38] The basis of our modeling approach is the unsaturated zone hydrology model for Yucca Mountain developed by our colleagues on the Yucca Mountain Project at Lawrence Berkeley National Laboratory (LBNL) [*CRWMS*, 2000b]. Earlier versions of this model are presented by *Wu et al.* [1999] and *Bodvarsson et al.* [1999]. From this LBNL model we take the three-dimensional definition of hydrostratigraphic units, including position of the water table and surface topography; thermohydrologic properties for these units; and model boundary conditions. The model includes 35 units, each of which is considered to be homogeneous with respect to thermal and hydrologic properties. These hydrologic properties are determined through an inverse thermal properties are determined on the basis of laboratory measurements.

[39] The LBNL unsaturated zone hydrology model [illegible] tration values based on studies by the United States Geological Survey [see *Flint et al.*, 1996]. The model assumes that present-day infiltration flux varies spatially, with a mean value of 6 mm yr^{-1}. The largest infiltration rates occur along the crest of Yucca Mountain where alluvial cover is thinnest, and the lowest rates occur along the flanks where alluvial cover is thickest. The model assumes that future climates become progressively wetter [illegible] present climate.

[40] We also take the conceptualization for flow through unsaturated fractured rock at Yucca Mountain from the LBNL unsaturated zone hydrology model. The current conceptual model is based on a dual-permeability representation of overlapping fracture and matrix continua, modified from the traditional approach such that only a portion of connected fractures actively conduct liquid water [*Liu et al.*, 1998], a portion which depends on [illegible] saturation in the fractures. There are two fundamental limitations of the traditional dual-permeability approach. First, it does not account for field and laboratory observations that suggest that only a portion of the connected fractures actively conduct liquid water under ambient conditions [see *Doughty*, 1999]. Second, it does not account for changes in fracture-matrix interaction due to the dynamic effects of heat-driven condensate flow [illegible] ambient infiltration (i.e., due to climate change). The [illegible]

Table 3. Thermohydrologic Properties of Engineered In-Drift Materials

Property	Units	Backfill	Invert	Waste Package	Drip Shield
Permeability	m^2	1.43E−11[a]	6.15E−10		
Porosity	...	0.41	0.545	–	
van Genuchten α	Pa^{-1}	2.7523E−4	1.2232E−3	–	
van Genuchten n	...	2	2.7	–	–
Residual saturation	...	0.024	0.092	–	–
Grain density	$Kg\ m^{-3}$	2700	2530	8189.2	4501.72
Specific Heat	$J\ Kg^{-1}K^{-1}$	795.492	948	488.86	551.32
Thermal conductivity	$W\ m^{-1}K^{-1}$	0.33	0.66	14.42	20.55
Emissivity	...	0.93	0.93	0.80	0.63

[a] Read, for example, 1.43 E-11 as 1.43×10^{-11}.

model parameters and how these parameters were chosen, the reader is referred to the references listed in the previous few paragraphs and to a recent paper by *Flint et al.* [2001] which discusses the evolution of the conceptual model of unsaturated zone hydrology at Yucca Mountain to date. Understanding flow in unsaturated fractured media in general, and at Yucca Mountain specifically, remains a topic of active research.

[42] We must add the drifts and the engineered components inside the drifts to the unsaturated zone hydrology model discussed above. The geometric configuration of the engineered components inside the drifts and thermohydrologic properties that correspond to those components considered in this modeling study are presented in Figures 4 and 5 and Table 3.

4.3. Governing Equations

[43] Our model solves the balance equations for air, water, and energy components for liquid and gas fluid phases and a non-

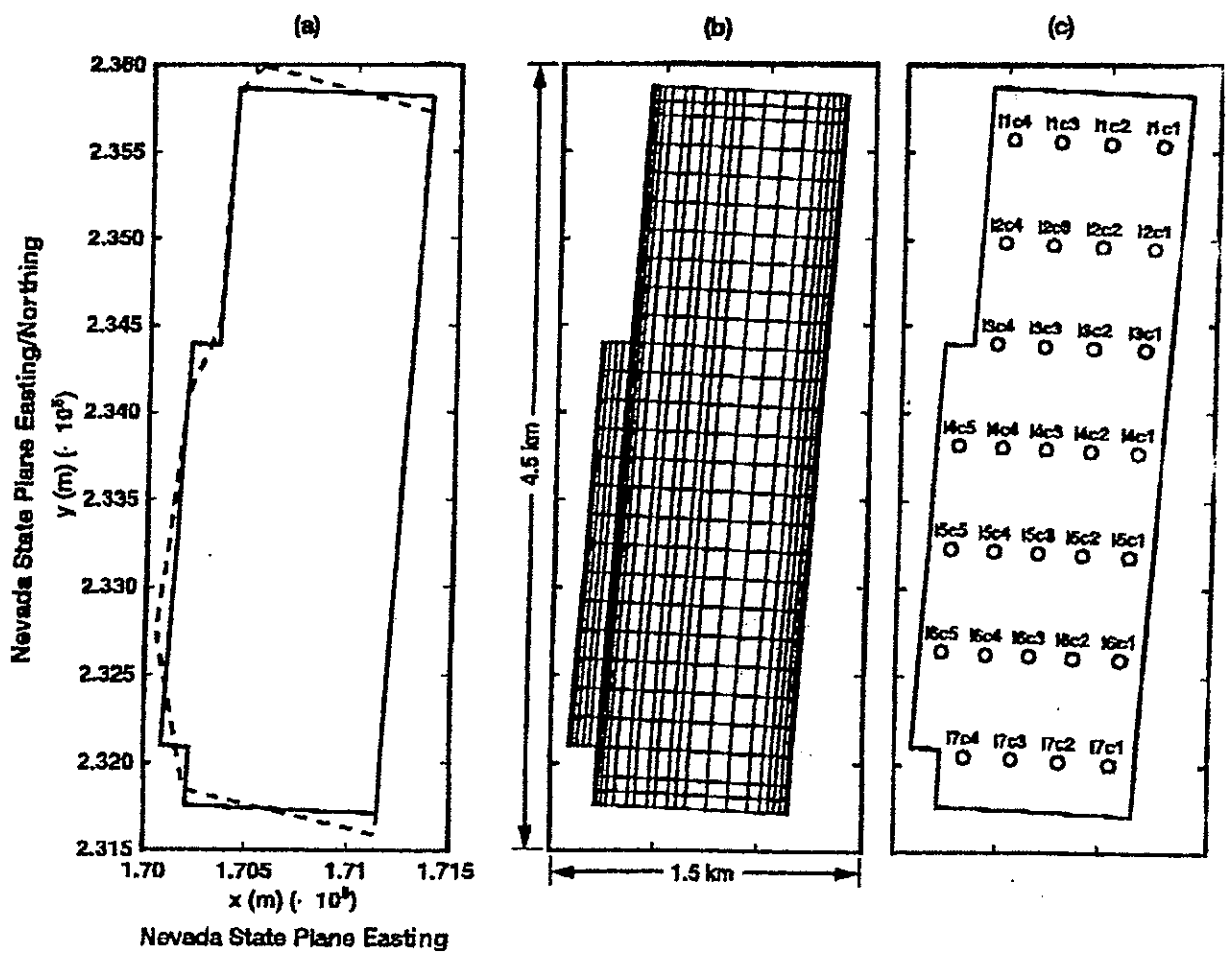

Figure 6. (a) Comparison of the actual repository footprint (dashed line) and the approximation of the repository

deformable solid. The balance equations for the air and water components are

$$\frac{\partial}{\partial t}\sum_{\alpha}\phi\rho_{\alpha}S_{\alpha}\omega_{\alpha}^{\gamma} = -\sum_{\alpha}\nabla\cdot\phi\rho_{\alpha}S_{\alpha}\left(\omega_{\alpha}^{\gamma}V_{\alpha} + J_{\alpha}^{\gamma\alpha}\right), \quad (1)$$

where t denotes time, the γ denotes a component (i.e., air and water), and α denotes fluid phases (e.g., liquid and gas). The combined diffusive and dispersive fluxes are given by Fick's law,

$$J_{\alpha}^{\gamma} = -D_{\alpha}^{\gamma}\nabla\omega_{\alpha}^{\gamma}. \quad (2)$$

The advective flux is given by Darcy's law,

$$S_{\alpha}\phi V_{\alpha} = -\frac{k_{\alpha}(S_{\alpha})}{\mu_{\alpha}}(\nabla p_{\alpha} + \rho_{\alpha}g\nabla z), \quad (3)$$

where z denotes distance in the vertical direction. The capillary pressure relationships are given by

$$p_{\alpha} = p_g - p_c. \quad (4)$$

The symbol ω_{α}^{γ} denotes mass fraction of γ component in phase α, S_{α} is saturation of α phase, ϕ is porosity, ρ_{α} is phase density, V_{α} is advective phase velocity, J_{α}^{γ} is combined diffusive and dispersive flux, D_{α}^{γ} is combined diffusion and dispersion coefficient, τ_{α} is tortuosity factor, k_{α} is permeability function, μ_{α} is phase viscosity, p_{α} is phase pressure, g is gravitational acceleration, and p_c is retention pressure function. In addition to the balance equations we have the constraints

$$\sum_{\gamma}\omega_{\alpha}^{\gamma} = 1 \quad (5)$$

$$\sum_{\alpha}S_{\alpha} = 1. \quad (6)$$

Local thermodynamic equilibrium is assumed between all phases. Partitioning of components between phases is expressed in terms of partitioning coefficients,

$$n_{\alpha}^{\gamma} = K_{\alpha,\beta}^{\gamma}n_{\beta}^{\gamma}, \quad (7)$$

where n_{α}^{γ} is mole fraction and K is the partitioning coefficient. For predicting the partitioning of water between the fluid phases the model includes the "vapor pressure lowering" effect based on the Kelvin law.

[44] The balance equation for energy is

$$\frac{\partial}{\partial t}\left[\sum_{\alpha}\phi\rho_{\alpha}u_{\alpha}S_{\alpha} + (1-\phi)\rho_s C_p(T - T_{ref})\right]$$
$$= \sum_{\gamma}\sum_{\alpha}\left[\nabla\cdot\phi h_{\alpha}^{\gamma}\rho_{\alpha}S_{\alpha}\left(\omega_{\alpha}^{\gamma}V_{\alpha} + J_{\alpha}^{\gamma\alpha}\right)\right] + \nabla\cdot K_H\nabla T, \quad (8)$$

where T denotes temperature, C_p is specific heat of solid, ρ_s is solid density, u_{α} is specific internal energy, h_{α}^{γ} is partial specific

open repository drifts in which waste packages are placed. In this case the surfaces of the drift wall and waste package are subdivided into surface elements, each of which is mapped to a computational volume element. Radiative flux is calculated for connections between each pair of surface elements using temperatures from the corresponding volume element. The net radiative heat transferred between two model nodes is calculated from the Stefan-Boltzmann law $Q = c(T_1^4 - T_2^4)$, where T_1 is the absolute temperature of the radiator, T_2 the absolute temperature of the receiver, and c is a coefficient defined by $c = AF\epsilon\sigma$, where A is the area of the radiating surface element, F is the radiative view factor [*Holman*, 1990], ϵ is emissivity, and σ is the Stefan-Boltzmann constant.

[46] The balance equations (1) and (8) are discretized in space using the integrated finite difference method and discretized in time using the fully implicit backward Euler method. The nonlinear system of equations is solved at each time step using the Newton-Raphson method.

[47] Our model utilizes a dual-permeability approach in which the fracture and matrix systems are treated as two separate continua with a complete set of balance equations and computational grid for each continuum. Each continuum has coupling terms for mass and energy fluxes between the two continua. These terms have the general form

$$q_{exchange} = a\kappa\Delta u/L, \quad (9)$$

where $q_{exchange}$ is flux of mass or energy per unit bulk volume, Δu is the difference in pressure or temperature between the continua and κ is a transfer coefficient. The coefficient κ for advective flux is of the form Kk_r/μ, where K is saturated permeability, k_r is relative permeability, and μ is viscosity. For diffusive mass flux of a phase, κ is equal to the apparent diffusion coefficient $D_{app} = \phi S\tau D$, where ϕ is porosity, S is saturation, τ is tortuosity factor, and D is the free diffusion coefficient. For energy flux, κ is the bulk thermal conductivity K_H. In the conventional dual-permeability approach a is the surface area of the fracture walls per unit bulk volume, and L is the average distance between centers of the matrix elements which is proportional to the fracture spacing. We use a fracture model modification to the traditional dual-permeability approach in which a and L are modified to account for inactive fractures (or portions of fractures) as suggested by *Liu et al.* [1998]. Specifically, a is multiplied by S_e, and L is multiplied by $S_e^{-\gamma}$, $S_e = (S_l - S_r)/(S_{max} - S_r)$ and S_r and S_{max} are residual and maximum liquid saturations, respectively.

[48] The relationships between permeability, saturation, and capillary pressure are described by the formulations of *van Genuchten* [1980] and *Mualem* [1976], modified to account for the active fracture model by the parameter γ which has a value between 0 and 1 (0 if all fractures are active). The relative permeability for the liquid phase is given by

$$k_{rl} = S_e^{(1+\gamma)/2}\left[1.0 - \left(1.0 - S_e^{(1-\gamma)/m}\right)^m\right]^2. \quad (10)$$

It is assumed that $k_{rl} + k_{rg} = 1$; the subscripts "l" and "g" refer to the liquid and gas phases, respectively. The capillary pressure is given by

$$p_c = \frac{1}{\alpha}\left(S_e^{(\gamma-1)/m} - 1\right)^{(1/n)}. \quad (11)$$

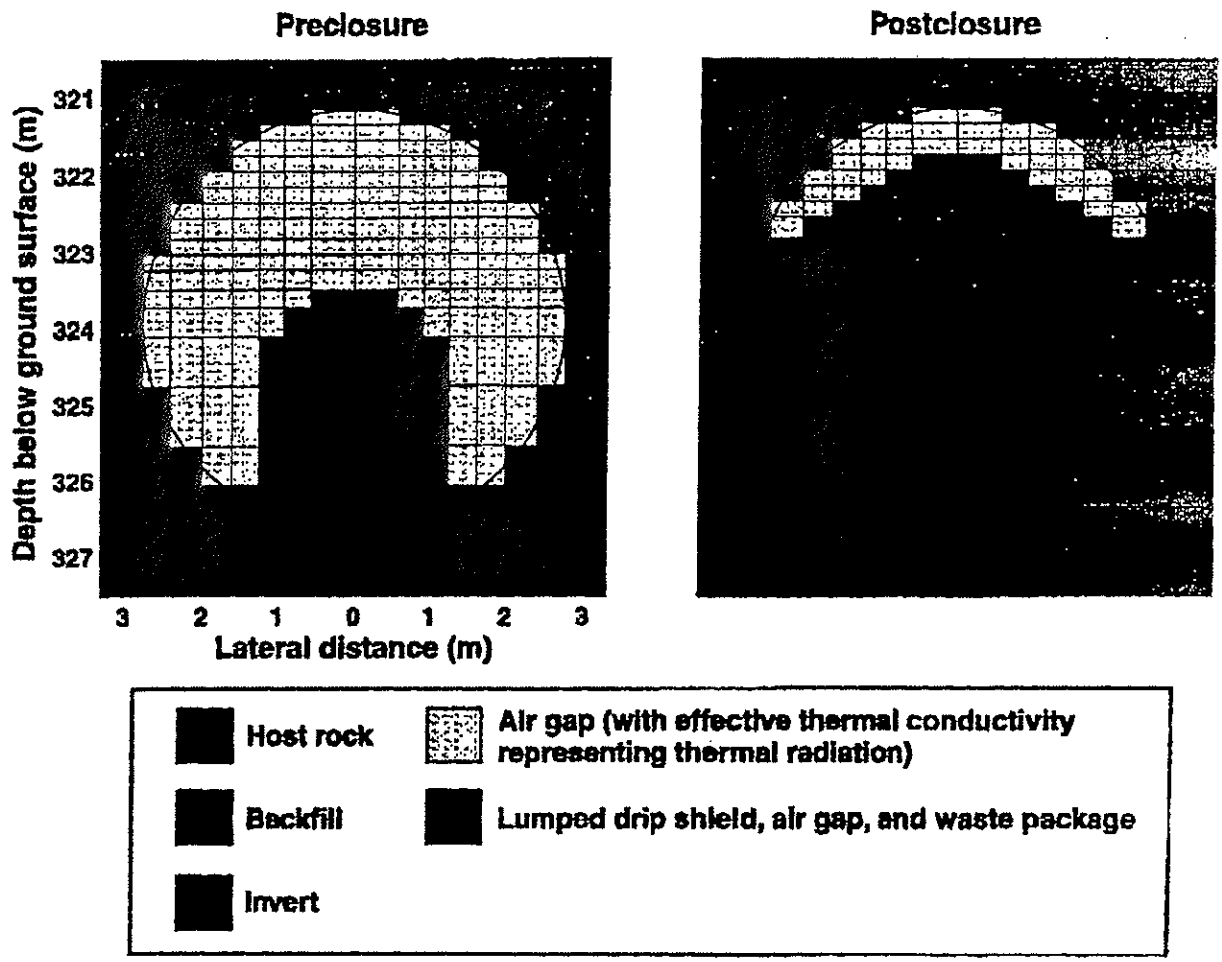

Figure 7. Close-ups of drift regions for both preclosure and postclosure LDTH submodels (14c3 location, see Figure 6). Note that the postclosure model shown corresponds to cases with backfill. For cases without backfill the postclosure grid is the same as the preclosure grid.

[49] The parameters used in this model are functions of pressure p, temperature T, mass fraction ω, and/or saturation S as follows: $\rho_\alpha(p,T,\omega)$, $D^\gamma_\alpha(p,T)$, $\mu_\alpha(p,T,\omega)$, $K^\gamma_{\alpha\beta}(p,T,S)$, $u_\alpha(p,T,\omega)$, $h^\gamma_\alpha(p,T)$, $k_\alpha(S)$, $\tau_\alpha(S)$, and $p_c(S,T)$.

[50] These equations are solved using the NUFT computer code [*Nitao*, 1998]. NUFT has been used to model thermohydrologic behavior for several major thermal field tests at Yucca Mountain to date. These tests include a single heater test in an alcove in the Exploratory Study Facility constructed underground at Yucca Mountain [*Tsang and Birkholzer*, 1999], a large block test conducted above ground in a block of repository horizon rock, and a long-term drift-scale test, also in the Exploratory Study Facility [*Birkholzer and Tsang*, 2000].

4.4. Multiscale Thermohydrologic Model (MSTHM)

[51] The MSTHM consists of four families of submodels of various scale, dimensionality, heat source representation, and assumptions regarding both the heat transfer processes considered and the coupling of heat transfer to fluid flow. The results of the four families of submodels are integrated to create the MSTHM results. The current version of the MSTHM consists of the (LDTH) submodel, (3) a one dimensional (1-D) smeared heat source, drift-scale, thermal conduction (SDT) submodel, and (4) a 3-D discrete heat source, drift-scale, thermal conduction (DDT) submodel.

[52] The LDTH submodel domain is a 2-D drift-scale cross section extending from the ground surface to the water table. The LDTH submodels are the only submodels to include coupled thermohydrologic processes. These submodels are run for different locations spaced evenly throughout the repository area (31 in this case, see Figure 6) and use the stratigraphy, overburden thickness, thermohydrologic boundary, and infiltration fluxes appropriate for each location. They assume a heat generation history that is effectively that of a line-averaged waste package averaged for the entire waste package inventory in the repository. Close-ups of the drift regions of the LDTH submodel grids, both preclosure and postclosure, are shown in Figure 7.

[53] The 3-D SMT submodel accounts for the actual repository footprint and the site-scale stratigraphy in Yucca Mountain, allowing treatment of mountain-scale heat flow, including the influence of overburden thickness and the edge-cooling effect. This submodel assumes a heat generation history that

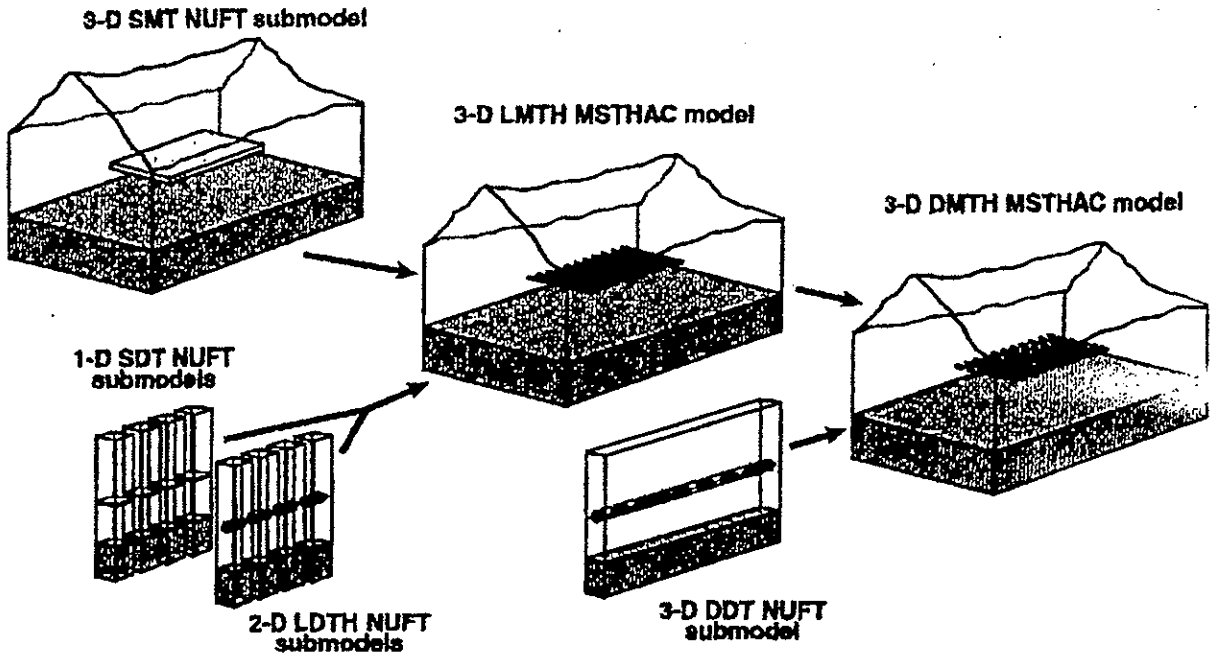

Figure 8. Cartoon of Multiscale Thermohydrologic Model (MSTHM). MSTHM consists of a family of four NUFT-based submodels of various scales, dimensionality, and processes, which are integrated with the Multiscale Thermohydrologic Abstraction Code (MSTHAC).

as the LDTH submodels. In effect, every LDTH submodel is paired up with a corresponding SDT submodel. The SDT submodels utilize the same heat generation history as the LDTH submodels except that it is areally smeared over the repository plane in the SDT submodels.

[54] Output from the SMT submodel, together with the pairs of LDTH and SDT submodels, are integrated to create the 3-D line-averaged heat source, mountain-scale thermohydrologic (LMTH) model. The DDT submodel is then used to further modify the LMTH model to account for waste package-specific deviations from average waste package behavior and the role of thermal radiation in open drifts. The end result is a 3-D discrete heat source, mountain-scale, thermohydrologic (DMTH) model (Figure 8).

[55] The MSTHM calculates thermohydrologic variables at a variety of locations (e.g., drift wall, drip shield, waste package, and various locations in the near-field host rock) for numerous geographic locations in the repository (610 in the example presented here, as shown in Figure 6) and different waste packages, as a function of time for each calculational time step. Thermohydrologic output variables include temperature, relative humidity, liquid-phase saturation (in the matrix and in the fractures), liquid-phase flux, gas-phase air mass fraction, gas-phase pressure, capillary pressure, gas-phase (water vapor) flux, gas-phase (air) flux, and evaporation rate. More detail about the submodels and how they are integrated is given below.

[56] The submodels are integrated with a tool called the Multi-Scale ThermoHydrologic Abstraction Code (MSTHAC) after all the appropriate submodel simulations have been run. We need to run two series of LDTH submodels, one each for preclosure and postclosure configurations, since all repository designs that we backfill) within the emplacement drifts. In each series of LDTH submodels we need to run submodels at 31 LDTH repository locations, for each of five different areal heat generation levels. This is 310 (31×5×2) LDTH submodels in all. Similarly, we also run 310 SDT submodels. Two SMT submodels are needed, one for preclosure heating conditions and one for postclosure heating conditions. Two DDT submodels are needed as well, one each for preclosure and postclosure conditions.

[57] We note that this approach can easily be extended or varied. For example, we have run MSTHM models using coupled thermohydrologic-chemical submodel (LDTHC) in place of the [illegible] submodel to explore the role of mineral precipitation and [illegible]tion on repository performance. Similar models could be run to investigate coupled thermohydrologic-mechanical processes.

[58] Two potentially important processes that the current MSTHM approach does not represent are mountain-scale lateral diversion of condensate above the repository and mountain-scale, buoyant, gas-phase convection. (The influence of drift-scale buoyant gas-phase convection is included in the current MSTHM approach.) The first process only potentially affects globally [illegible]ing design concepts; it does not affect locally boiling and subboiling repository concepts, which are becoming the focus of modeling and performance assessment studies for a potential Yucca Mountain repository.

[59] The results of previous modeling studies [*Buscheck and Nitao*, 1994] suggest that mountain-scale buoyant gas-phase convection begins to significantly influence heat flow (and temperatures in the repository) only if the bulk permeability is above a threshold value of 10 darcies; on the basis of data available to date the bulk permeability values in the potential host rock units at Yucca Mountain are below this threshold value. Moreover for

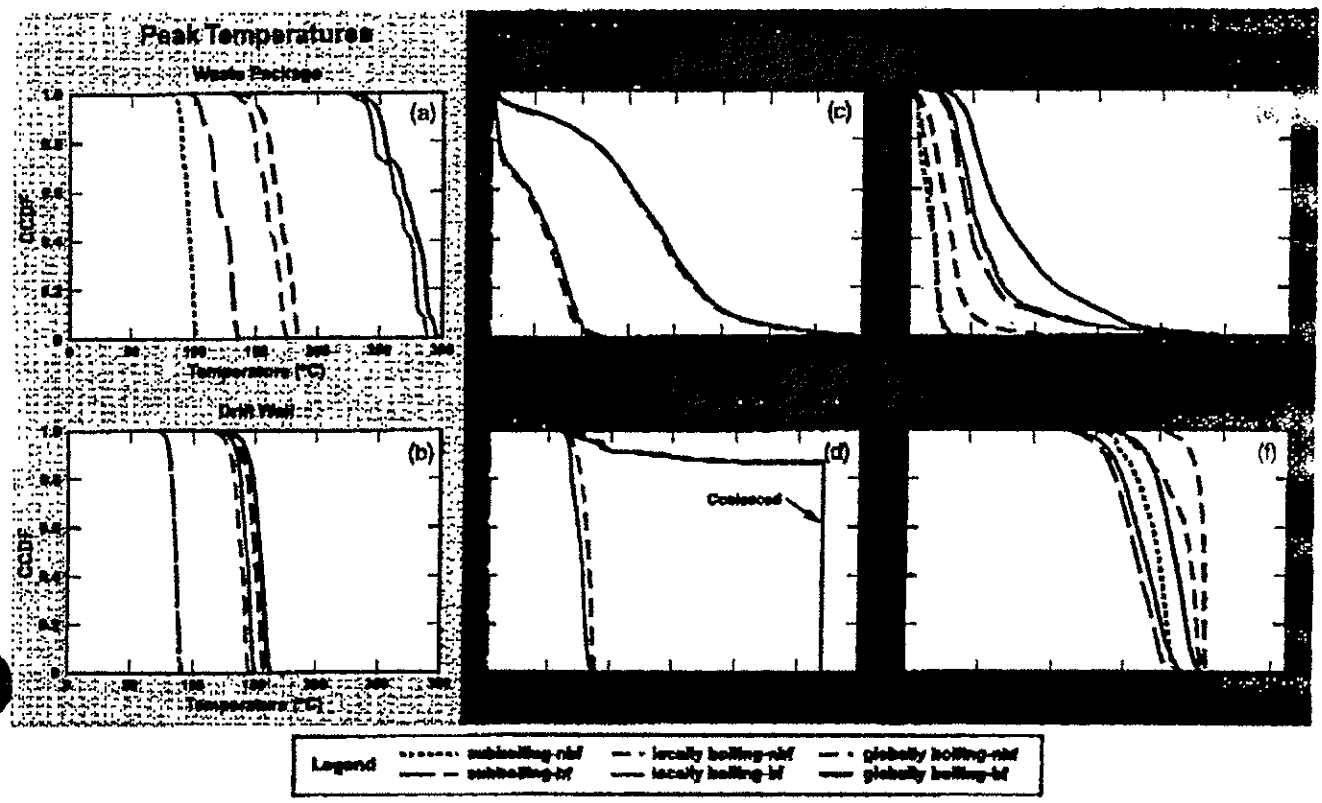

Figure 9. Complementary cumulative distribution function (CCDF) plots for the six different thermal designs considered in this study (Table 3). These CCDF plots include the nearly 5000 combinations of waste package types and repository locations considered in the MSTHM. The value corresponding to a CCDF value of 0.5 represents the value that half of the combinations of the waste packages and repository locations fall below. The assumed infiltration flux is the mean flux case. The abbreviations "bf" and "nbf" in the legend denote the backfill and no-backfill cases, respectively.

zontal anisotropy in the bulk permeability distribution tend to break up and thereby reduce the influence of mountain-scale gas-phase convection cells. This gives us confidence that neglecting mountain-scale, buoyant, gas-phase convection in our models is a reasonable assumption. To test the reasonableness of this assumption, we plan to conduct future MSTHM calculations that incorporate the results of a smeared heat source, mountain-scale, thermohydrologic (SMTH) submodel (rather than those of an SMT submodel) thereby fully addressing the influence of mountain-scale, buoyant, gas-phase convection.

5. Modeling Results and Discussion

[60] We present model results comparing the six different repository designs considered (Table 2) in the form of six complementary cumulative distribution function (CCDF) plots (Figure 9). These CCDF plots include the nearly 5000 combinations of waste package types and repository subdomain locations considered in the MSTHM (610 repository subdomain locations multiplied by eight waste package type equals 4880 combinations).

[61] Figure 9a provides information on peak waste package temperature, and Figure 9b provides information on peak perim-

return to the boiling point after peak drift wall temperatures have occurred (Figure 9c) and the maximum lateral extent of boiling in the host rock in the plane of the waste packages (Figure 9d). The final two plots concern relative humidity reduction. The first of these is a plot of the time it takes for the relative humidity on the waste package surface to return to 80% after the initial dry out period (Figure 9e). The second is a plot of the temperatures of the waste packages at this time (Figure 9f).

[62] To illustrate how to interpret these CCDF plots, consider the CCDF plot for the peak waste package temperature (Figure 9a). The temperature corresponding to a CCDF value of 1 represents the lowest peak waste package temperature for all 4880 combinations of waste packages and repository locations; all waste packages have a peak temperature that is at least this hot. The temperature corresponding to a CCDF value of 0.5 represents the peak waste package temperature of the median waste package; half of the waste packages have a higher peak waste package temperature and half have a lower peak waste package temperature. The temperature corresponding to a CCDF value of 0 represents the highest peak temperature for all 4880 combinations of waste packages and repository locations. We consider the three designs without backfill first (Figure 9).

(Figure 9b), between 72° and 90°C (as was required for this design). The locally boiling repository design has peak drift wall temperatures between 116° and 146°C. The globally boiling repository design has peak drift wall temperatures that are a few degrees higher, between 118° and 159°C. The peak waste package temperatures in all cases are below 300°C (Figure 9a). The subboiling design has peak waste package temperatures between 79° and 104°C. For 61% of the waste packages in the subboiling design the peak waste package temperature is below the boiling point. The locally boiling repository design has peak waste package temperatures of between 128° and 178°C. The globally boiling repository design has peak waste package temperatures a few degrees higher, between 130° and 186°C.

5.1.2. Above-boiling conditions in host rock. [64] The host rock in the subboiling repository design remains subboiling (as was required for this design by definition), so these CCDF curves plot as straight lines at 0 years (Figure 9c) and 0 m (Figure 9d), respectively. The locally boiling repository design has a maximum extent of boiling of ~9 m, indicating that less than one fourth of the host rock at the repository horizon ever experiences above-boiling conditions. Half of the waste packages have returned to subboiling drift wall conditions in less than 520 years, and all have returned to subboiling drift wall conditions after 1200 years. The duration and extent of above-boiling conditions in the host rock is the greatest for the globally boiling designs. In the globally boiling designs the boiling zones coalesce for ~87% of the possible combinations of waste packages and repository locations. There is a broad distribution in the duration of boiling at the drift wall for the globally boiling design (Figure 9c), with half of the waste packages still experiencing above-boiling conditions in the drift wall at 1700 years. The longest duration of boiling is 3840 years. The shortest duration of boiling is only 64 years.

5.1.3. Relative humidity reduction. [65] The duration of reduced relative humidity on waste packages is similar for the subboiling and locally boiling repository designs (Figure 9e). For the subboiling design the time required for waste packages to return to RH = 80% ranges from 55 to 1580 years, with the median waste package taking 615 years. For the locally boiling design the time required for the waste packages to return to RH = 80% ranges from 160 to 1460 years, with the median waste package taking 680 years. For the globally boiling design the time required for waste packages to return to RH = 80% ranges from 160 to 4350 years, with the median waste package taking 1170 years. The temperatures at the time at which waste packages return to RH = 80% are lowest for the subboiling design and highest for the globally boiling design (Figure 9f). For the subboiling repository design the temperature at the time that waste packages return to RH = 80% ranges from 56° to 94°C and is 87°C for the median waste package. For the locally boiling design, this temperature ranges from 56° to 102°C and is 97°C for the median waste package. For the globally boiling design this temperature ranges from 68° to 104°C and is 102°C for the median waste package.

5.2. Adding Backfill

[66] Next, we consider adding backfill to the subboiling, locally boiling and globally boiling designs considered above. These results show that the duration and extent of boiling conditions in the host rock is not significantly affected by the presence of

[67] The addition of backfill, however, causes a significant increase in peak temperature on waste packages (Figure 9a). For the locally boiling and globally boiling designs, the addition of backfill increases peak waste package temperatures [illegible] while for the subboiling design the increase is only [illegible] For all designs the addition of backfill greatly affects relative humidity reduction on waste packages (Figures 9e and 9f). Reduced relative humidity conditions occur long after boiling ceases in the backfill designs, while for the designs without backfill, reduced relative humidity conditions do not persist long after the end of the boiling period.

[68] Adding backfill increases the duration of reduced relative humidity conditions for all waste packages (Figure 9e). For the subboiling backfill design the time required for waste packages to return to RH = 80% ranges from 630 to 12,090 years, with the median waste package taking 1810 years. For the locally boiling backfill design this ranges from 660 to 12,140 years, with the median waste package taking 1990 years. Note that the median waste packages in the subboiling and locally [illegible] backfill designs stay drier longer than the majority of waste packages (88% and 92%, respectively) in the globally boiling no-backfill design. For the globally boiling backfill design the time required for waste packages to return to RH = 80% ranges from 680 to 11,990 years, with the median waste package taking 2820 years. Note that the lower and upper ends of the CCDFs are quite similar for all three backfill designs. The distinction is that the median waste package in the [illegible] boiling design takes 56% and 41% longer to attain RH [illegible] than the median waste packages in the subboiling and locally boiling designs, respectively. Note also that the last waste package that reaches RH = 80% takes longer to reach that point in the subboiling and locally boiling designs than in the globally boiling design. The fact that the ratio of relative humidity on the waste package to relative humidity [illegible] wall for a given temperature difference between these two surfaces decreases as the absolute temperature on the waste package decreases (Figure 2) makes a lower-temperature backfill design particularly effective with respect to relative humidity reduction.

[69] The addition of backfill lowers the temperatures at which relative humidity values return to 80% for all [illegible] (Figure 9f); as for the no-backfill cases, temperatures are [illegible] for the subboiling design and highest for the globally boiling design. For the subboiling repository design with backfill the temperature at the time at which waste packages return to RH = 80% ranges from 52° to 92°C and is 79°C for the median waste package. For the locally boiling design this temperature ranges from 52° to 96°C and is 82°C for the median waste package. For the globally boiling design this temperature ranges [illegible] to 103°C and is 92°C for the median waste package. With regard to this performance measure the subboiling and locally boiling designs perform similarly, and the globally boiling design is considerably hotter.

[70] We want to stress that the material properties of the backfill critically affect thermohydrologic behavior in the drifts. We have assumed a single-layer backfill of coarse sand with low capillarity (i.e., its tendency to wick water inward is [illegible] model. A single-layer fine sand with high capillarity will not perform as well with respect to relative humidity reduction on waste packages.

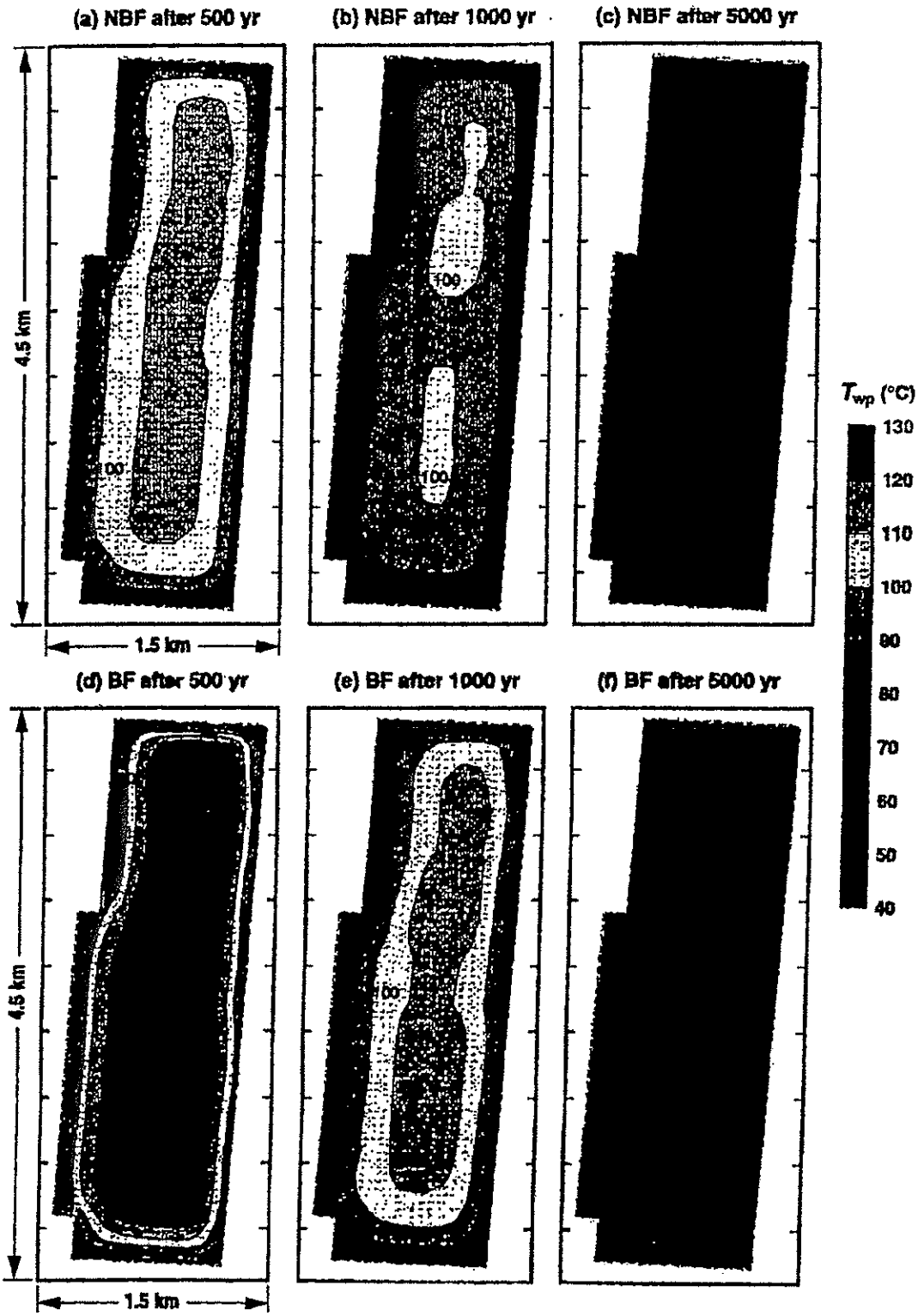

Figure 10. Contours of waste package temperatures at three different times for the locally boiling designs (a–c) with no backfill (NBF) and (d–f) with backfill (BF). The assumed infiltration flux is the mean-flux case. See color version of this figure at back of this issue.

waste packages from focused "drips" and relative humidity reduction. Unfortunately, it is a fact that a single-layer backfill achieves attenuation of focused seepage, but because it may wick water from fractures in the host rock, it may increase the total

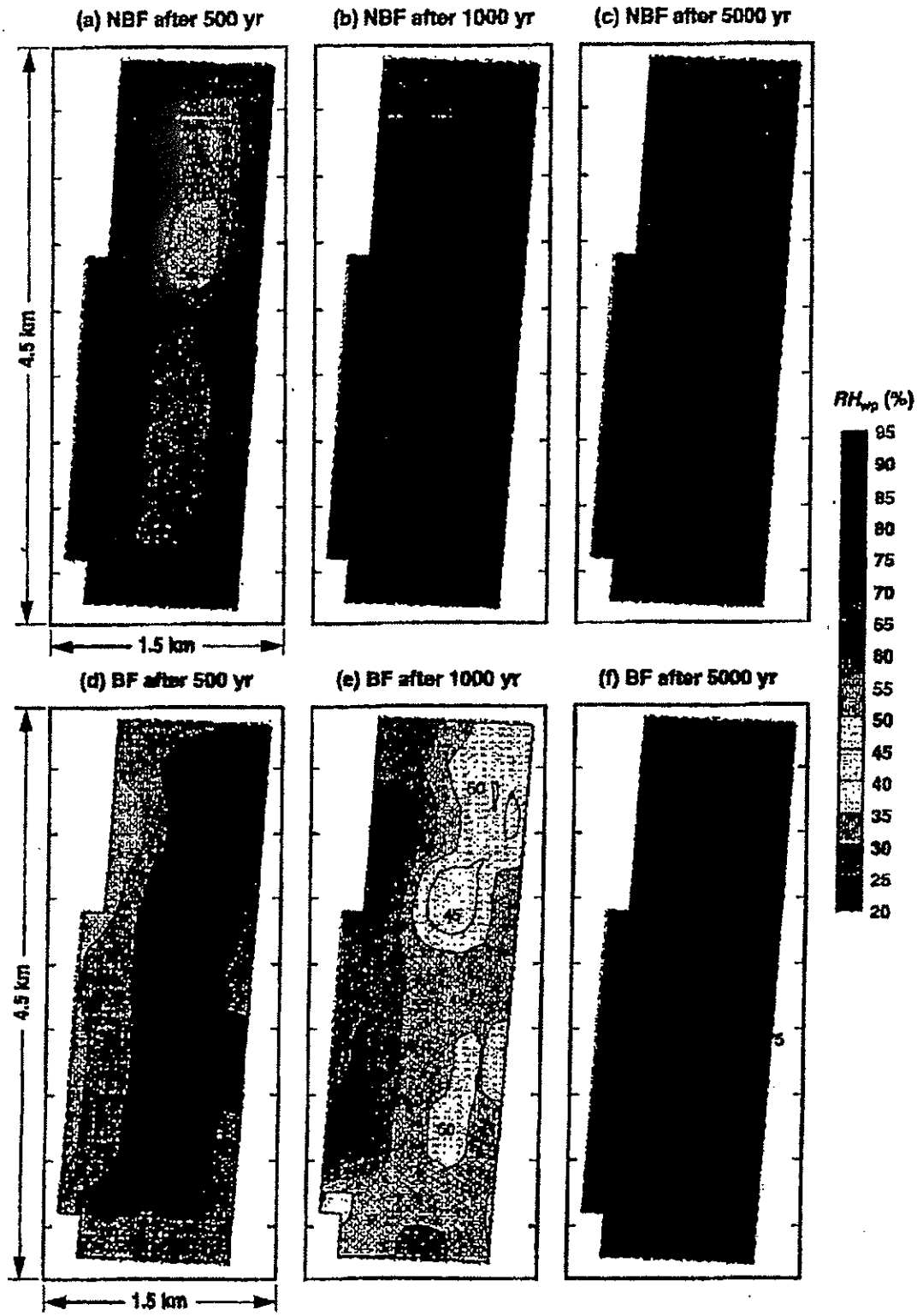

Figure 11. Contours of waste package relative humidity at three different times for the locally boiling designs (a–c) with no backfill (NBF) and (d–f) with backfill (BF). The assumed infiltration flux is the mean-flux case. See color version of this figure at back of this issue.

functions are achievable [*Buscheck et al.*, 1999]. A capillary barrier would allow seepage flow to be attenuated by the upper layer (fine

5.3. Design Trade-Offs

[72] These model results (Figure 9) illustrate the trade-offs

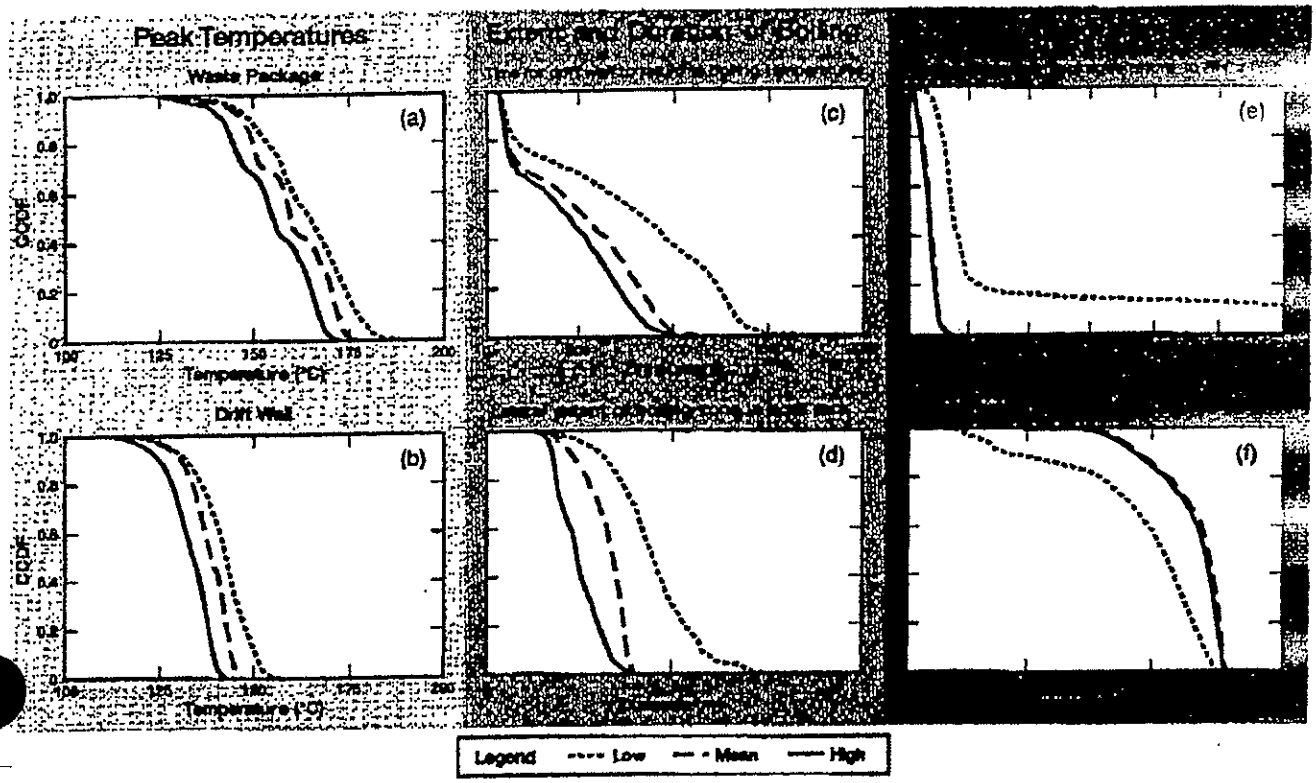

Figure 12. CCDF plots (showing the sensitivity of locally boiling no-backfill design to uncertainty in the infiltration rate. The mean-flux case is the same as that considered in Figure 9.

the locally boiling and globally boiling designs (Figure 9a). For the subboiling backfill design, peak waste package temperatures are markedly lower than in the local boiling and globally boiling designs; however, these lower temperatures are achieved at the cost of an additional 150 years of drift ventilation (200 versus 50 years). A subboiling no-backfill repository design does a good job of eliminating boiling conditions in the host rock and keeping waste package temperatures to a minimum but at the expense of a relatively short duration of relative humidity reduction on waste packages. A globally boiling no-backfill repository does a good job extending the duration of relative humidity reduction but at the expense of an extensive boiling zone in the host rock.

5.4. Variability in Thermohydrologic Behavior

[73] For many of the repository designs we considered in the modeling described above, the CCDF curves (Figure 9) are quite broad. This reflects the significance of variation in repository location, waste package type, or both on thermohydrologic behavior and illustrates a very important point, which is that there is a range of repository thermohydrologic behavior and that as a result, repository thermohydrologic behavior is not well represented by a few "typical" geographic locations in the repository. Recall that variation in geographic location in the repository reflects differences in stratigraphy, overburden thickness, thermal boundary conditions, and local infiltration fluxes, as well as differences in proximity to the edge of the repository. Consideration of this entire range of thermohydrologic behavior rather than that arising from parameter values occurring at a "typical" repository location is infirm, and young children in evaluations of risk rather than focus only on the response of a healthy, middle-aged person.

[74] The range of above-boiling conditions experienced for a given repository design is a function mainly of location within the repository. For a given design, waste packages located in the 20% of the repository nearest the repository edges experience the shortest duration and least spatial extent of above-boiling conditions, mainly as a result of the edge-cooling effect. Waste packages located in the 20% of the repository closest to the center experience the longest duration and greatest spatial extent of above-boiling conditions. Edge-cooling effects, which are initially confined to the outer edges of the repository, influence a progressively wider region at the edges with time. Waste package type is a second-order factor, with the duration and extent of above-boiling conditions greatest for the hottest waste packages.

[75] The range of drift wall temperatures for a given repository design is a function of location within the repository (with temperatures decreasing with proximity to the repository edge) and waste package type (with higher heat output waste packages having higher temperatures). The range of peak waste package temperatures for a given repository design is primarily a function of waste package type, with the hottest waste packages (PWR commercial spent nuclear fuel) having the highest peak temperatures. For a single waste package type, waste package temperatures vary as a function of location within the repository with temperatures decreasing with proximity to the repository edge; this is particularly true after edge-cooling effects have had a chance to propagate inward toward the center of the repository. Figure 10

location and the contribution of backfill to waste package temperatures are clearly shown in Figure 10.

[76] The waste packages with the longest duration of reduced relative humidity conditions are the higher heat output waste packages at the repository center. Figure 11 illustrates the distribution in relative humidity conditions on the waste package surface at several times for the locally boiling designs, with and without backfill, for a single waste package type. Values of relative humidity are clearly lowest in the repository center and greatest at the repository edges, and relative humidity values are lower when backfill is present. The range in the temperature at the time at which waste packages return to RH = 80% for a given repository design is mainly a function of location within the repository, with the highest temperatures at the repository center and the lowest at the repository edges.

5.5. Sensitivity to Uncertainties in the Natural System

[77] Since repository performance is a function of both the engineered system and the natural system, assumptions about key natural system factors strongly affect predictions about repository thermohydrologic behavior. To examine the effect of different infiltration fluxes on thermohydrologic behavior, we performed simulations for the locally boiling, no-backfill case for infiltration fluxes both higher and lower than the fluxes considered previously (the mean-flux case). In all cases, infiltration fluxes vary spatially across the repository. For the low-, mean-, and high-flux cases, infiltration flux increases as a step function at 600 years, with this increase varying as a function of location. For the mean- and high-flux cases, infiltration flux increases further at 2000 years, while it decreases somewhat for the low-flux case. The average values over the repository area for present-day climate fluxes which occur during the first 600 years are 0.56, 6.0, and 15 mm yr^{-1} for the low-, mean-, high-flux cases. Results of the sensitivity of thermohydrologic behavior to infiltration flux are shown in Figure 12 and discussed below.

[78] The influence of infiltration flux on peak waste package and drift wall temperatures is shown in Figures 12a and 12b. Peak temperatures are highest for the low-flux case and lowest for the high-flux case. The extent of rock dry out increases with decreasing infiltration flux. Because the thermal conductivity of the rock decreases with liquid-phase saturation, a larger dry out zone results in a greater temperature rise in the near-field host rock; consequently, peak temperatures are greatest for the low-flux case and least for the high-flux case. Temperature are ~5°C higher for the mean-flux case than the low-flux case. Temperatures are 5°C lower for the high-flux case than the mean-flux case.

[79] The duration of the boiling period in the host rock decreases with increasing infiltration flux, which is shown in the CCDF of the time at which the drift wall declines below boiling (96°C) (Figure 12c). For the median waste package location (CCDF = 0.5) this time is 808, 518, and 439 years for the low-, mean-, and high-flux cases, respectively. The spatial extent of boiling conditions also decreases with increasing infiltration flux (Figure 12d). For the median waste package location (CCDF = 0.5) the maximum lateral extent of boiling is 7.4 m, 8.3 m, and 9.3 m for the high-, mean-, and low-flow cases, respectively.

[80] The low-flux case results in more persistent relative humidity reduction on waste packages than the mean- and high-flux cases, which show similar behavior to each other (Figure 12e). The mean- and high-flux cases have similar waste package temperatures. These results imply that an infiltration-flux threshold value above which further degradation in the duration of relative humidity reduction is negligible and that the values for the mean-flux case considered here approach this threshold value for the boiling repository design. Further increases in infiltration flux (above the mean-flux case) have a diminishing effect on degrading the duration of relative humidity reduction on waste packages.

[81] For this study we did not explicitly examine the effects of other, less important, natural system factors that affect the thermohydrologic environment. However, on the basis of previous work [e.g., *Buscheck*, 1998] we offer the following observations. In general, drift wall and waste package temperatures decrease with increasing thermal conductivity of the local host rock unit because heat is transmitted more rapidly into the rock. Overburden thickness is unimportant at early time when the vertical temperature gradient has not interacted with the ground surface boundary. [illegible] repository edges where the edge-cooling effect is more dominant. The greatest long-term temperature rise occurs at near-center locations with thick overburden (at locations approximately one third of the way from the western repository boundary). Lower matrix imbibition diffusivity and fracture capillarity in the local host rock reduce the rewetting rate at the dry out front; consequently, these favor more extensive boiling and dry out in the host rock and more persistent relative humidity reduction in the host rock and in the emplacement drifts.

6. Conclusions

[82] The emplacement of heat-generating nuclear waste in a geologic repository such as the one being considered at Yucca Mountain will change the thermal and hydrologic [illegible] significantly, affecting thermohydrologic conditions both in the near-field host rock and within the emplacement drifts. The thermally driven flow of water vapor away from the heat source causes a redistribution of the pore fluids within a potentially large volume of rock, creating rock dry out around the emplacement drifts and condensation zones outside of the dry out zone.

[83] The engineering design variables that affect thermohydrologic behavior at an underground geologic repository for [illegible] waste such as the one being considered at Yucca Mountain include (1) overall areal heat generation density of the waste inventory, (2) average lineal heat generation density along the drifts, (3) distance between drifts, (4) age of the nuclear waste at emplacement, (5) location of repository horizon in the subsurface, (6) repository footprint, (7) waste package spacing (line load versus point [illegible]), (8) waste package sequencing (with respect to the heat output of individual waste packages), (9) duration and heat removal efficiency of drift ventilation, and (10) in-drift design and emplaced engineered materials (e.g., backfill and drip shields).

[84] Factors in the natural system that affect thermohydrologic behavior include (1) the infiltration flux, (2) thermohydrologic properties (thermal conductivity, matrix imbibition diffusivity, fracture capillarity), (3) overburden thickness, and (4) conditions at the ground surface.

[85] There are a large number of ways in which these variables and factors can be combined, but thermohydrologic behavior to first order is well described by a few major attributes. These are as follows: whether boiling or subboiling conditions occur in the host rock, whether or not the boiling zones around individual drifts coalesce, the degree of nonuniformity of heating [illegible]

[86] The interaction between the various engineering design variables and natural system factors is highly nonlinear, and therefore repository designs that differ by seemingly small amounts (in overall areal heat generation density of the waste inventory, for example) can result in markedly different thermohydrologic behavior in the near-field host rock and in the emplacement drifts; these differences can result in significantly different performance of the repository system. In other cases, rather large differences may have little or no effect. Decisions about repository design and assessments of repository performance must consider the complex, nonlinear relationship between engineering design variables and natural system factors in light of realistic expectations for construction tolerances and uncertainties and variation in the natural system.

[87] We have identified four major thermal design goals for a subsurface nuclear waste repository. Three concern the environmental conditions that the waste packages will experience. These include keeping temperatures below critical temperatures for engineered materials, limiting water seeping into drift, and keeping waste packages dry (i.e., low relative humidity) until cool (with respect to threshold temperatures). The fourth goal is the reduction of uncertainty in process-model predictions that support repository performance assessment, which has been interpreted by some to require eliminating boiling in the host rock and possibly within the emplacement drift. We have evaluated the trade-offs in terms of meeting these goals for six different repository designs, chosen to illustrate a wide range of repository thermohydrologic behavior: subboiling, locally boiling, and globally boiling designs, each with and without backfill.

[88] These trade-offs can be summarized as follows. The presence of backfill increases the duration of relative humidity reduction on waste packages significantly but at the cost of higher waste package temperatures. Drift wall temperatures are not significantly affected by backfill. A subboiling, no-backfill repository design eliminates boiling conditions in the host rock but at the expense of a shorter duration of relative humidity reduction on waste packages. A globally boiling repository extends the duration of relative humidity reduction but at the expense of an extensive boiling zone in the host rock.

[89] We note that the repository design currently being considered by the Yucca Mountain Project (the locally boiling design without backfill) is flexible in several ways. Without any changes in the initial construction, repository operation could be modified decades or even centuries later to significantly change thermohydrologic behavior and repository performance if circumstances (new data or new understanding) should warrant such a change. For example, by simply extending the ventilation period from 50 years to 200 years, the locally boiling design becomes a subboiling design. Also, if a decision is made to increase performance with respect to relative humidity reduction on waste packages, backfill could be added.

[90] We also considered uncertainties with respect to the natural system. The most important parameter of the natural system influencing design performance is infiltration flux; therefore we considered a single design using three different infiltration fluxes. These model results show that, in general, repository performance improves as infiltration fluxes decrease, but they also illustrate the nonlinearity of the system in that for some measures (relative humidity reduction), performance ceases to be affected by further increases in infiltration above a threshold value. We also discussed the effect on model output of changing the assumed values used for

[91] We have demonstrated a multiscale modeling approach to assessing thermohydrologic behavior at Yucca Mountain. This approach accounts for processes occurring at a scale of a few tens of centimeters around individual waste packages and emplacement drifts and also for behavior at the scale of the mountain. This modeling approach, however, is more than an efficient equivalent of adaptive grid or "telescoping" models. Our approach captures the natural variability of the site consistent with what we know from site characterization and full 3-D dimensionality. It also captures the full 3-D dimensionality of the details of the engineered components inside the emplacement drifts, as well as the variability in heat output from different waste packages. We have shown that this variability has a significant impact on thermohydrologic behavior at Yucca Mountain. Of particular importance is location within the repository with respect to repository edges. The broad range in the values for repository performance measures predicted by this approach underscores the limitations of a modeling approach based on a limited number of typical repository locations. The ability of the multiscale approach to capture some of the complexity of the coupled natural/engineered system and its computational efficiency make it a powerful and unique performance assessment and engineering design tool for geologic repository systems.

References

Bandurraga, T. M., and G. S. Bodvarsson, Calibrating hydrogeologic parameters for the 3-D site-scale unsaturated zone model of Yucca Mountain, Nevada, *J. Contam. Hydrol.*, *38*(1–3), 25–46, 1999.

Birkholzer, J. T., and Y. W. Tsang, Modeling the thermal-hydrologic processes in a large-scale underground heater test in partially saturated fractured tuff, *Water Resour. Res.*, *36*(6), 1431–1447, 2000.

Bodvarsson, G. S., W. Boyl, R. Patterson, and D. Williams, Overview of scientific investigations at Yucca Mountain—The potential repository for high-level nuclear waste, *J. Contam. Hydrol.*, *38*(1–3), 3–24, 1999.

Buscheck, T. A., Thermohydrologic models, in *Near-Field/Altered Zone Models Report*, edited by E. L. Hardin, *Rep. UCRL-ID-129179*, Lawrence Livermore Natl. Lab., Livermore, Calif., 1998.

Buscheck, T. A., and J. J. Nitao, Repository-heat-driven hydrothermal flow at Yucca Mountain, Part 1, Modeling and analysis, *Nucl. Technol.*, *104*(3), 418–448, 1993.

Buscheck, T. A., and J. J. Nitao, The impact of buoyant, gas-phase flow and heterogeneity on thermo-hydrological behavior at Yucca Mountain, in high level radioactive waste management, paper presented at Fifth Annual International Conference, Am. Soc. of Civ. Eng., Las Vegas Nev., 1994.

Buscheck, T. A., J. J. Nitao, and L. D. Ramspott, Localized dryout: An approach for managing the thermal-hydrological effects of decay heat at Yucca Mountain, in *Scientific Basis for Nuclear Waste Management XX*, pp. 715–722, Mater. Res. Soc., Pittsburgh, Pa., 1995.

Buscheck, T. A., J. J. Nitao, and L. D. Ramspott, Near-field thermal-hydrological behavior for alternative repository designs at Yucca Mountain, in *Scientific Basis for Nuclear Waste Management XX*, pp. 1029–1036, Mater. Res. Soc., Pittsburgh, Pa., 1996.

Buscheck, T. A., J. Gansemer, J. J. Nitao, and T. H. Delorenzo, Multi-scale near-field thermohydrologic analysis of alternative designs for the potential repository at Yucca Mountain, in *Scientific Basis for Nuclear Waste Management XXII*, pp. 615–622, Mater. Res. Soc., Pittsburgh, Pa., 1998.

Buscheck, T. A., N. D. Rosenberg, and Y. Sun, The role of a capillary barrier in the geologic disposal of nuclear waste (abstract), *Eos Trans. AGU*, *80*(46), *Fall Meet.* Suppl., F314, 1999.

Civilian Radioactive Waste Management System (CRWMS), Total system performance assessment-viability assessment (TSPA-VA) analyses technical basis document, *Rep. B00000000-01717-4301 REV 01*, TRW Environ. Safety Syst., Inc., Las Vegas, Nev., 1998.

Civilian Radioactive Waste Management System (CRWMS), Total system performance assessment-site recommendation methods and assumptions, *Rep. TDR-MGR-MD-000001 REV 00*, TRW Environ. Safety Syst., Inc., Las Vegas, Nev., 1999a.

Civilian Radioactive Waste Management System (CRWMS), Thermohydrologic calculations for site recommendation/license application design

thermohydrologic model, *Rep. ANL-EBS-MD-000049 REV 0*, TRW Environ. Safety Syst., Inc., Las Vegas, Nev., 2000a.

Civilian Radioactive Waste Management System (CRWMS), Unsaturated zone flow and transport model process model report, *Rep. TDR-NBS-HS-000002 REV00 ICN02*, Manag. and Oper. Contract., Las Vegas, Nev., 2000b.

Doughty, C., Investigation of conceptual and numerical approaches for evaluating moisture, gas, chemical, and heat transport in fractured unsaturated rock, *J. Contam. Hydrol.*, *38*(1–3), 69–106, 1999.

Flint, A. L., J. A. Hevesi, and E. L. Flint, Conceptual and numerical model of infiltration for the Yucca Mountain area, Nevada, *U.S. Geol. Surv. Water Resour. Invest. Rep.*, *96*, 1996.

Flint, A. L., L. E. Flint, G. S. Bodvarsson, E. M. Kwicklis, and J. Fabryka-Martin, Evolution of the conceptual model of unsaturated zone hydrology at Yucca Mountain, Nevada, *J. Hydrol.*, *247*, 1–30, 2001.

Haukwa, C. B., Y. S. Wu, and G. S. Bodvarsson, Thermal loading studies using the Yucca Mountain unsaturated zone model, *J. Contam. Hydrol.*, *38*(1–3), 217–255, 1999.

Holman, J. P., *Heat Transfer*, 7th ed. McGraw-Hill, New York, 1990.

Liu, H. H., C. Doughty, and G. S. Bodvarsson, An active fracture model for unsaturated flow and transport in fractured rock, *Water Resour. Res.*, *34*(10), 2633–2646, 1998.

Montazar, P., and W. E. Wilson, Conceptual hydrologic model of flow in the unsaturated zone, Yucca Mountain, Nevada, *U.S. Geol. Surv. Water Resour. Invest. Rep.*, *84–4345*, 1984.

Mualem, Y., A new model for predicting the hydraulic conductivity of unsaturated porous materials, *Water Resour. Res.*, *12*(3), 513–522, 1976.

Nitao, J. J., Reference manual for the NUFT flow and transport code, version 2.0, *Rep. UCRL-MA-130651*, Lawrence Livermore Nat. Livermore, Calif. 1998.

Pruess, K., J. S. Y. Wang, and Y. W. Tsang, On thermohydrologic conditions near high-level nuclear wastes emplaced in partially saturated fractured tuff, 1, Simulation studies with explicit consideration of fracture effects, *Water Resour. Res.*, *26*(6), 1235–1248, 1990a.

Pruess, K., J. S. Y. Wang, and Y. W. Tsang, On thermohydrologic conditions near high-level nuclear wastes emplaced in partially saturated fractured tuff, 2, Effective continuum approximation, *Water Resour. Res.*, *26*(6), 1249–1261, 1990b.

Tsang, Y. W., and J. T. Birkholzer, Multi-phase thermal hydrological processes in the single heat test at Yucca Mountain, *J. Contam. Hydrol.*, *38*(1–3), 385–425, 1999.

van Genuchten, M. T., A closed-form equation for predicting the hydraulic conductivity of unsaturated soils, *Soil Sci. Soc. Am. J.*, *44*, 892–898, 1980.

Wu, Y.-S., C. Haukwa, and G. S. Bodvarsson, A site-scale model for fluid and heat flow in the unsaturated zone of Yucca Mountain, Nev., *J. Contam. Hydrol.*, *38*(1–3), 185–215, 1999.

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ENCLOSURE

#6

SECTION 8

UCRL-ID-139027

Maxey-Eakin Methods for Estimating Groundwater Recharge in the Fenner Watershed, Southeastern, California

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Maxey-Eakin Methods for Estimating Groundwater Recharge in the Fenner Watershed, Southeastern, California.

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Abstract
Recent review comments by the U.S. Geological Survey, Water Resources Division on the Cadiz Groundwater Storage and Dry-Year Supply Program Draft Environmental Planning Report were accompanied by an independent recharge estimate to the Fenner Basin based on a Maxey-Eakin method. The following report has analyzed WRD's recharge estimates and concludes that those results greatly underestimate annual recharge and lack credibility. Among the reasons outlined are 1) WRD's lack of geographic scale and context when analyzing precipitation-elevation data, 2) WRD's use of an un-calibrated Maxey-Eakin model, and 3) WRD's lack of direct observational experience in the eastern Mojave-Fenner Basin region. This report presents a more exhaustive analysis of data, supported by direct field observations, and estimates recharge using a calibrated Maxey-Eakin model. This report concludes that the possible range in annual groundwater replenishment rates to the Fenner Basin are between 7864 acre-ft and 29,185 acre-ft. The lower limit is a worst-case-scenario. This range is consistent with original recharge estimates calculated and presented in the Cadiz Groundwater Storage and Dry-Year Supply Program Draft Environmental Planning Report.

Introduction
As part of a drought mitigation strategy and long-term planning for beneficial use of imported Colorado River water, the Metropolitan Water District (MWD) of southern California investigated the feasibility of storing river water in groundwater aquifers of the eastern Mojave Desert. This effort has culminated in the production and public release of the Cadiz Groundwater Storage and Dry-Year Supply Program Draft Environmental Planning Report, Groundwater Resources, Volumes I and II (Draft EIR). In particular, MWD and Cadiz Inc. contracted to Geosciences Support Services Inc. to perform pilot percolation studies, groundwater modeling, and precipitation/runoff analysis in the Fenner groundwater basin, which overlies the proposed storage site (Fig. 1). The project proposes to store and withdrawal Colorado River water over a 50-year period. During periods of groundwater withdrawal, MWD is committed to *not* exceed the natural replenishment rates of the groundwater basin. As part of a plan to insure that this will not happen, several independent analyses were conducted to estimate the rates of natural groundwater replenishment to the Fenner Groundwater Basin, which was included in the Draft EIR.

During the public comment period for the Draft EIR, the U.S. Geologic Survey, Water Resources Division (WRD) officially submitted comments. It was their conclusion that the natural groundwater replenishment rates calculated for the Draft EIR were too high. In the WRD review, they provided an independent recharge calculation based on a Maxey-Eakin estimation approach.

The authors of this current report, under the auspices of Lawrence Livermore National Laboratory (LLNL), were asked to provide an analysis of WRD's Maxey-Eakin estimation. It is the conclusion of this report, that the recharge estimate by the WRD is unreasonably low. Their low estimate was due to 1) inadvertent exclusion of key data and underestimation of local precipitation, 2) underestimation of local groundwater recharge rates, and 3) use of an un-calibrated Maxey-Eakin recharge model.

Estimation of Annual Rainfall by WRD

The basic premise of a Maxey-Eakin recharge estimate is that the rate of groundwater replenishment is proportional to the annual rainfall. The method is best suited for arid environments, where high elevations typically experience much greater annual rainfall than low elevations. Recharge estimates using a Maxey-Eakin method requires predicting how precipitation (rain and snow) varies with elevation change on an annual basis in localized areas. From these data, a percentage of annual precipitation will contribute to groundwater recharge. Hence, a Maxey-Eakin model predicts recharge as a function of precipitation.

For the Fenner Basin a reasonable approach would be to plot mean annual precipitation data against its elevation collected at relevant sites. A curve can be fitted to this data to provide a quantitative means to calculate annual precipitation at various elevations. Note that the higher the slope on a precipitation-elevation curve, the higher the groundwater recharge estimate. However, previous attempts to create precipitation-elevation curves in western Nevada have been difficult and result in large uncertainty (for example, see Hevesi et al., 1992, and references therein).

In WRD's review comments on the Draft EIR, they presented a precipitation-elevation plot that included a variety of data points from southeastern California (Fig. 2). It should be noted that the data they selected does not represent the entire range of elevations contributing to groundwater recharge in the Fenner basin. In particular, their data only includes points less than 1500 meters elevation, however, the Providence and New York mountains in the Fenner basin both exceed 2000 meters. Although data from these sites do not exist, their ultimate exclusion will contribute to erroneous results.

In the WRD analysis of their data, they separated from the database four points that were in close proximity to the Fenner basin. They "visually" fitted an independent curve to these four points and a mathematical curve to the remainder of the database. In the case of the four data points, the slope of the curve was much higher than the curve fitted to the remainder of the data. WRD concluded that the higher slope was "unrealistic", but provided no evidence to support this conclusion. Subsequently, they favored the lower slope fitted to the remainder of the data even though these data are farther from the Fenner basin and show considerable scatter around the fitted curve.

Estimation of Annual Rainfall by LLNL

Several environmental factors complicate the distribution of rainfall throughout southeastern California and western Nevada. For example, the Sierra Nevada, San Gabriel, and San Bernadino mountains create a dramatic rain shadow effect that limits annual rainfall the east. In addition, winter storms originating from the Pacific Ocean have different trajectories and can produce locally intense snow and/or rain, but exclude other areas depending on its path. Furthermore, summer storms originating from the Gulf of California produce more annual precipitation in the eastern Mojave Desert, but much less in the western Mojave. In order to predict the annual precipitation as a function of elevation, the mechanisms that control the geographic distribution must be understood in

the context of these complications. In addition, the appropriate geographic scale needs to be represented in any data analysis, for which the WRD's data analysis lacks.

The strongest effect on annual precipitation in southeastern California and western Nevada is the rain shadow caused by the Sierra Nevada Mountains. The rain shadow effect will have its greatest intensity just east of the Sierra Nevada, and decrease in an eastward direction. The contribution of this effect extends eastward into Central Nevada. Therefore, the appropriate scale to understand the mechanism of rainfall distribution in southeastern California should include data from a large part of Nevada. Consequently, the relationship between annual precipitation and elevation should be controlled by east-west direction, or longitudinal position. This relationship has been recognized and documented by previous researchers, including the U.S. Geologic Survey, WRD (Winograd and Thordarson, 1975; see page C6 and references therein).

Below we plot annual precipitation and elevation data for weather stations throughout southeastern California and western to southern Nevada (Fig. 3; Table 1). This plot includes more data than used in the WRD analysis (Fig. 2), and unlike the WRD plot, it includes elevations in excess of 2000 meters. Like the WRD's plot, figure 3 isolates the same four data points in close proximity to the Fenner Basin, for which a mathematical curve has been fitted to the data. In addition, figure 3 separates the data into two groups: those data collected west of 116°W longitude, and those collected east of 116°W. This grouping of the data demonstrates an important east-west dependence on how annual precipitation varies as a function of elevation. In particular, those data closer to the Sierra Nevada (e.g. Western Mojave Desert) have significantly less annual precipitation at higher elevations than further east. The 116°W demarcation was used because it approximately coincides with a low elevation trend extending south from the Salton Sea trough and north toward Hot Creek Valley in Central Nevada. Prominent high elevation areas such as the Fenner watershed and the Spring Mountains lie east of 116°W, while the San Bernadino Mts., the Sierra Nevada, and the White Mts. lie to the west.

Mathematical curves fit to these two data groups, using an exponential function, shows an increasing slope with increasing distance from the Sierra Nevada. The quality of these curve fits is also good with R^2 regressions from 0.66 to 0.68. In addition, a curve was also fitted to the four data points used by the WRD for stations in the Fenner basin area. The curve fit for these data yielded a much higher slope, and predicts significantly higher precipitation rates at higher elevation.

The curve fit to data east of 116°W longitude illustrates the regional precipitation/elevation effect, which is given the term "*regional curve*". The Fenner Basin is a local area residing in this regional group. The *regional curve* describes the precipitation/elevation effect at a larger scale. At smaller scales (i.e. Fenner Basin), *local curves* with higher and lower slopes occur, that combined together form the *regional curve*. In figure 3, the four data points for the Fenner Basin area is one such example of a *local curve*. In this case, the four points form a higher slope than the regional curve, and represent the local, small-scale effect. Therefore, WRD's conclusion that the higher slope formed by the four points is "unrealistic" is not correct, but rather on the contrary, this

local curve more accurately reflects local conditions. It is, therefore, appropriate to use the steeper curve in figure 3 to calculate recharge to the Fenner basin. It is most appropriate to use the *regional curve* to calculate recharge to a larger, more regional area. Applying the *regional curve* to a local basin such as the Fenner Basin is an inappropriate matching of scales.

In figure 3, the curve fitted to data west of 116°W longitude demonstrates that for the western Mojave Desert the rate of precipitation with respect to elevation is far lower than in the eastern Mojave. This implies that recharge rates are significantly lower in the western Mojave than in the eastern Mojave. Almost all of WRD's experience on desert groundwater recharge is in the western Mojave Desert (see Fig. 1), as evident in their review comments and their consistent referral to that work. Based on figure 3, however, WRD's knowledge of western Mojave Desert groundwater is not translatable to the eastern Mojave, and these groundwater systems are not analogous by virtue of their different climate.

Scientific Basis for the Maxey-Eakin Method

The Maxey-Eakin method requires determination of both a precipitation rate and a recharge rate. Precipitation rates were estimated as a function of elevation (Fig. 3). Groundwater replenishment rates are estimated on the basis that some fraction of annual precipitation will recharge, and that fraction will increase with increasing elevation (Maxey and Eakin, 1949). This results in a hypothetical curve relating annual groundwater recharge to annual precipitation (Fig. 4)

Field validation of recharge rates is critical in order to establish credibility to any estimate. This is due to the fact that the Maxey-Eakin approach is empirical. An empirical model is derived from practical experience rather than basic theory. Therefore, a validated Maxey-Eakin model in one groundwater basin does not necessarily translate to a different one.

In the WRD's Maxey-Eakin model, they used a curve previously calibrated to three separate locations in *western* Nevada and applied it to the Fenner Basin (see Fig. 1). It is of particular importance to note that all three of the WRD's locations are *west* of longitude 116°W. As shown in an accompanying report, annual precipitation west of 116°W is significantly lower than east of 116°W. Therefore, the WRD's Maxey-Eakin curve was calibrated to a drier climate, and its application to the Fenner Basin lacks credibility.

Recharge Rates in the Fenner Watershed

As part of LLNL's analysis, a new Maxey-Eakin curve was developed using four independent field observations in the Fenner Basin (Fig. 4). Recharge rates to these four sites were determined by a hydrologic mass balance method, for which three of the sites have been calibrated to groundwater age dates. Detailed discussions of each calibration point are presented in the Appendix.

As can be seen in figure 4, the Maxey-Eakin curve developed for the Fenner Basin predicts significantly higher recharge rates than would be predicted by the WRD's curve. The differences in the two curves is expected since the Maxey-Eakin model is *empirical* and results will vary significantly between different geographic settings and between different geographic scales. The Fenner Basin curve is calibrated to field observation within project area basin, whereas the WRD's curve was calibrated outside the project area, at a larger scale, and in drier climates north and west of the Fenner Basin (Fig. 1).

LLNL Maxey-Eakin Recharge Estimates

Maxey-Eakin recharge estimates in the Fenner Basin require computing surface area as a function of elevation. These results are tabulated in Table 1 and were generated by digital methods. Average annual precipitation is then computed over the elevation range and is also presented in Table 1. Two precipitation-elevation curves were used: 1) the regional curve based on weather stations east of 116°W longitude in southeastern California and southern Nevada; 2) the local curve based on four stations nearby or within the Fenner Basin (Fig. 3). These curves encompass the possible range in annual precipitation in the Fenner Basin. However, the local curve is more relevant to the Fenner Basin due to its close proximity and its similar geographic scale.

The percent of annual precipitation that contributes to groundwater recharge is estimated from the Maxey-Eakin curve (Fig. 4). The Fenner Basin curve is used since it has been calibrated to four separate locations within the basin. No data exists on this curve for precipitation rates exceeding 380mm/yr. Therefore, a line is joined between the upper point of the Fenner Basin curve and the upper point of the WRD curve, which is used as an estimate of annual recharge for areas with precipitation rates exceeding 380mm/yr. However, the data points forming the Fenner Basin curve are linear over the range of observation and are used for all other recharge estimates.

The sum of annual recharge computed over the elevation range in Fenner Basin is presented in Table 1. The recharge rate is 16,214 acre-ft using the regional precipitation-elevation curve, and is 29,185 acre-ft using the local curve. Based on the methods and the available data, the 29,185 acre-ft estimate is a maximum recharge rate. However, assumptions used to calibrate the Maxey-Eakin curve for the Fenner Basin were based on conservative parameters (see Appendix). *Therefore, the maximum recharge rate could still be higher than 29,185 acre-ft per year.*

In Maxey-Eakin's original paper on recharge estimates (Maxey and Eakin, 1949), they assumed that no recharge occurred in areas receiving less than 200mm/yr (8in/yr) of precipitation. Although supporting evidence is lacking for this assumption, this report attempts to honor this notion by recalculating the annual recharge estimates in Table 1 and eliminating all potential recharge for areas less than 200mm/yr. This results in revised recharge estimates of 7864 acre-ft per year using the regional precipitation-elevation curve and 23,511 acre-ft using the local curve. Note that in eliminating areas of less than 200mm/yr precipitation, the annual recharge is still well within the range estimated by independent approaches outline in the Draft EIR.

In a risk-based analysis of the proposed groundwater storage project in Fenner Basin, the upper and lower limits of annual recharge are needed to assess potential environmental impacts. Based on the evidence and data analysis presented in this report, the possible range in annual recharge to the Fenner Basin is 7864 to 29,185 acre-ft per year. Based on the analysis, *the lower limit of 7864 acre-ft is a worse-case-scenario, and annual recharge is likely higher.*

The results of the LLNL Maxey-Eakin recharge estimates for the Fenner Basin differ greatly from those estimated by WRD in their review comments. They suggested recharge was between 2070 and 10,343 acre-ft per year for the Fenner Basin. They suggested the higher recharge rate was "unrealistic". However, their analysis and recharge estimate lacked 1) the geographic context set forth in this report, 2) a calibrated Maxey-Eakin curve, and 3) direct observational experience in the Fenner Basin. In their review comments, the WRD presented an interpretation that recharge rates should be low in the Fenner Basin. That interpretation was based on WRD's independent observations in the *western* Mojave Desert. As pointed out in this report, such comparisons lack credibility because of significant climate variability between the eastern and western Mojave Deserts.

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References

Hevesi, J.A., Istok, J.D., Flint, A.L., 1992, Precipitation estimation in mountainous terrain using multivariate geostatistics. Part I. Structural analysis. Jour. Appl. Meteorol., 31, 661-676.

Maxey, G.B. and Eakin, T.E., 1949, Groundwater in the White River Valley, White Pine, Nye, and Lincoln counties, Nevada. Water Resources Bulletin No. 8, State of Nevada, Office of the State Engineer.

Winograd, I.J. and Thordarson, W., 1975, Hydrogeologic and hydrochemical framework, south-central Great Basin, Nevada-California, with special reference to the Nevada Test Site. *U.S. Geol. Surv. Prof. Paper 712-C.* 126 pgs.

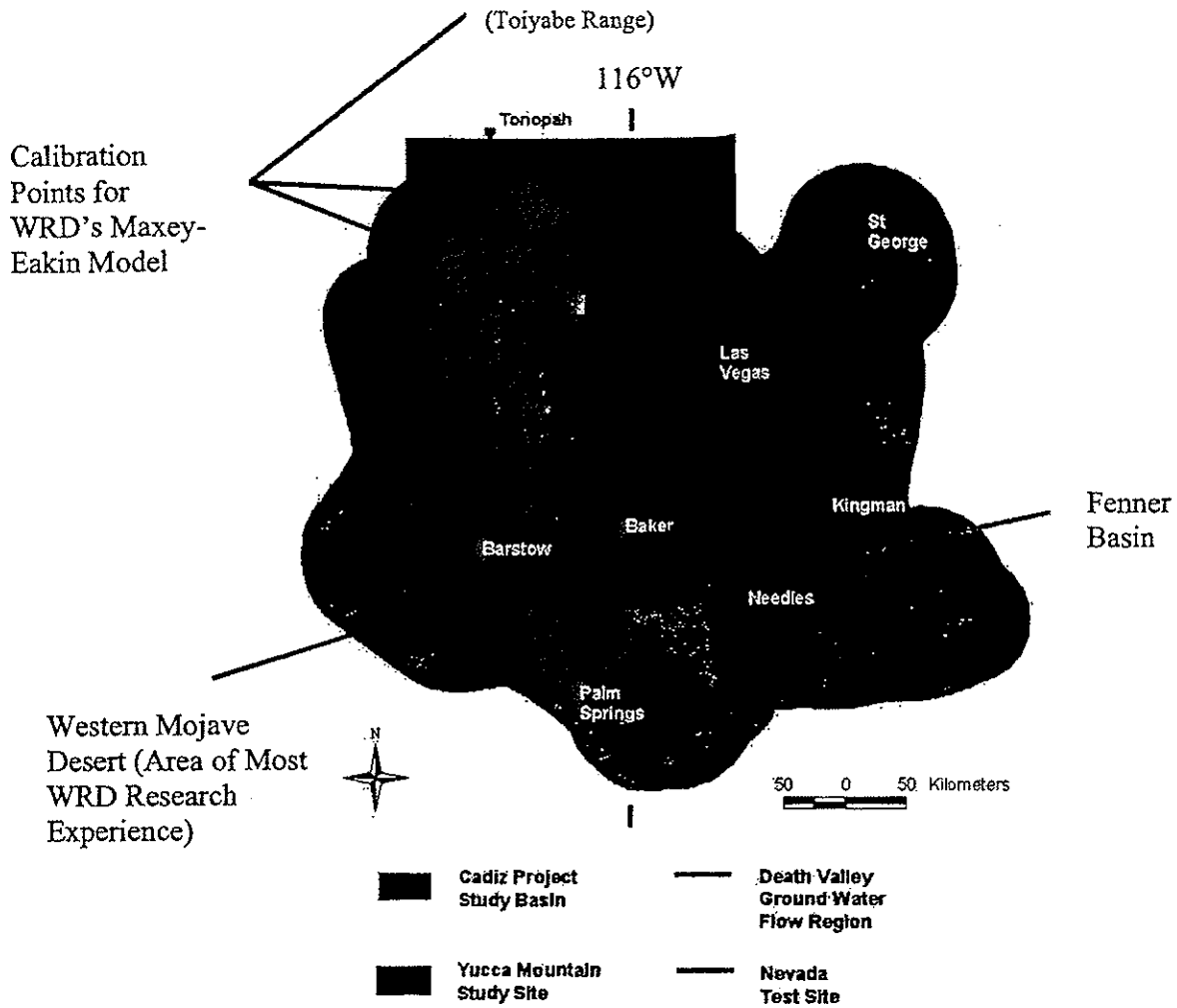

Figure 1. Proposed groundwater storage area is in the Fenner Basin.

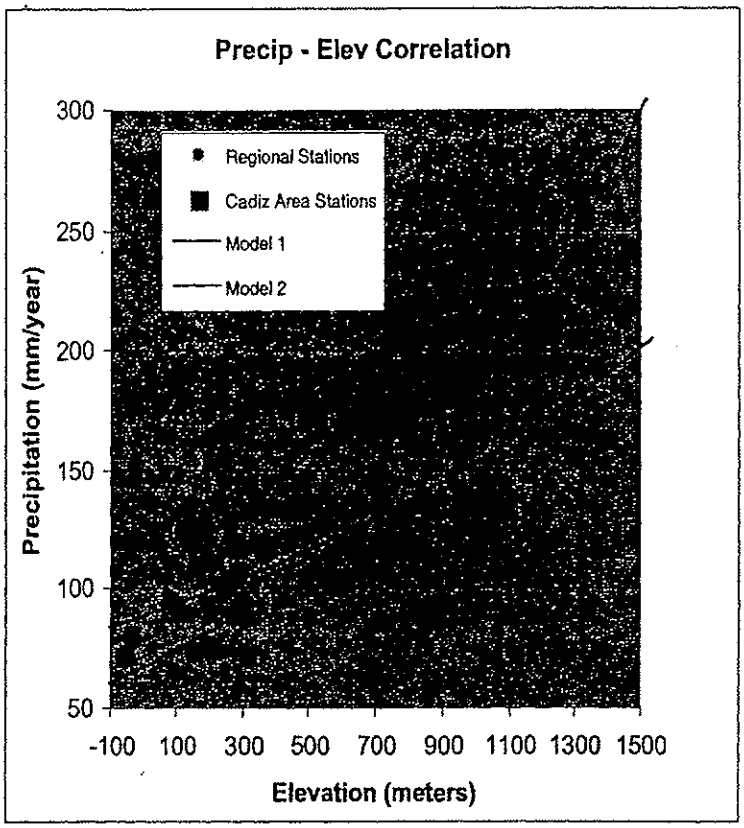

Figure 2. WRD's precipitation-elevation curves.

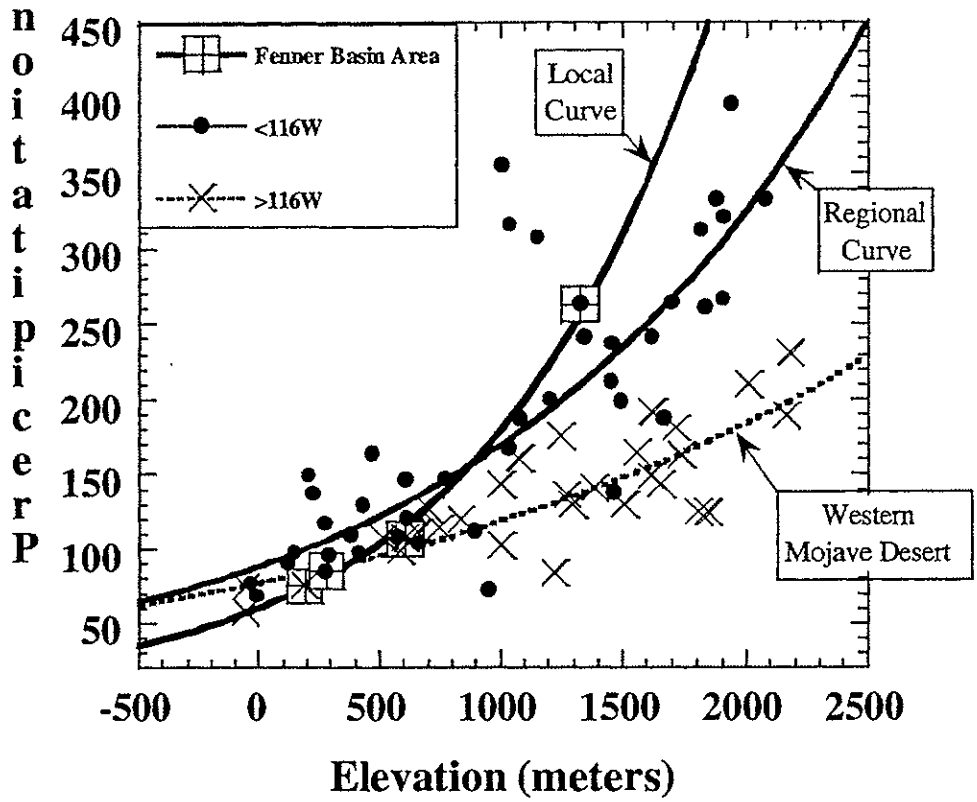

Figure 3. LLNL's precipitation-elevation curves.

Regional curve: $y = 88.6*e^{0.00065x}$
Local curve: $y = 60.1*e^{0.0011x}$

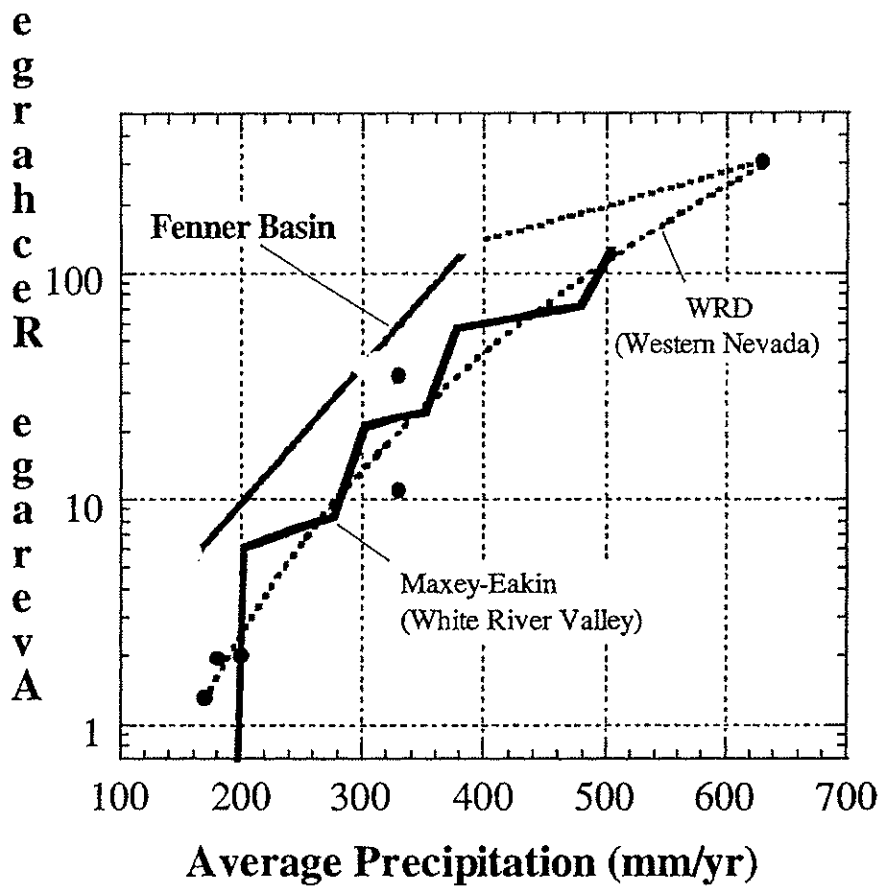

Figure 4. Maxey-Eakin curves used by LLNL, WRD, and Maxey-Eakin's original for the White River Valley, Nevada.

Appendix

Calculating recharge rates at individual groundwater well sites requires an estimation of the annual precipitation accumulating in the recharge area of each well, the aquifer volume of groundwater flowing past each well, and a groundwater age. Dividing the aquifer volume by the groundwater age provides an annual replenishment rate. That rate is compared to the annual precipitation rate and used as a calibrating point for the Maxey-Eakin curve. For a spring sample, the annual volume of spring discharge is simply compared to the annual precipitation rate accumulated in the spring's recharge area.

The recharge rates are estimates that require some assumptions about aquifer dimensions and recharge areas. In the following calculations, values for these parameters are chosen as to minimize the potential annual recharge. In doing so, the actual recharge rates may be higher than those calculated as final values.

Example #1

The first example is from a groundwater well in the Providence Mts. The well is located in the upper part of Gold Valley (35°5.9'N, 115°23.7'W). The well is reported to be completed in alluvium. This well was sampled and measured for radiocarbon age dating (Stephens and Associates, 1992). The radiocarbon abundance of the dissolved inorganic carbon had a "bomb-pulse" concentration (104 percent modern carbon), indicating that the groundwater was recharged less than 40 years ago. Bomb-pulse radiocarbon occurs in young groundwater due to surface testing of nuclear weapons, which injected an abnormal amount of radiocarbon into our atmosphere in the early 1960's.

This well has an estimated maximum recharge area of 12.9km^2 (5mi^2). The mean elevation of the recharge area is 1650m (5400ft), and the annual precipitation is estimated between 259mm/yr (10.3in/yr) and 365mm/yr (14.5in/yr), based on precipitation-elevation curves (Fig. 3). Therefore, the total annual precipitation accumulating in the recharge area is 2708 to 3817 acre-ft (3.3 to 4.7x10^6 m^3). We assume a minimum aquifer depth of 15m (~50ft), a mean porosity of 10%, and a groundwater age of 40 years. This results in an annual average recharge to the aquifer of 392 acre-ft (4.8x10^{5}m^3). Dividing this into the annual precipitation suggests that on average 10 to 15% of the annual precipitation recharges this area. This is equivalent to 40.3mm/yr (1.6in/yr).

Example #2

The second example is a well sampled by LLNL February 3, 2000 in Round Valley (Mid Hills area; 35°08'52.5", 115°21'28.8"; NE,SW1/4 sec3 T12N R15E). This well also had a bomb-pulse radiocarbon value (113 percent modern carbon). The well also had bomb-pulse tritium (16.7 pCi/L) originating from post-1963 precipitation. Its maximum recharge area is ~11.7km^2 (4.5mi^2). The mean elevation is ~1600m (5249ft), and a mean annual precipitation rate ranges from 251 to 346mm/yr (10 to 13.7in/yr). Assuming the same aquifer parameters and groundwater age as the first example, the calculated annual recharge rate is 11 to 15% of the annual precipitation, or 40mm/yr. This is nearly identical to the previous example.

Example #3

The third example is from the New York Mountains and a well located at the southern end of Caruthers Canyon (35°13'33.7"; 115°17'58.3"). Technically, Caruthers Canyon does not recharge the Fenner groundwater basin, but rather is thought to flow east towards the Colorado River. However, very similar canyons to the west in the New York Mountains (e.g. Fourth of July Canyon) provide recharge areas to the Fenner Basin. The well in Caruthers Canyon was sampled by LLNL February 3, 2000. This well also had bomb-pulse tritium (18.2 pCi/L), indicating recharge less than 40 years ago.

The recharge area for this well is 8.9km^2 (3.45mi^2). The mean elevation is estimated at 1875m (6150ft). Estimated annual precipitation is between 300 and 467mm/yr (11.9 to 18.5in/yr). This is equivalent to an annual accumulated precipitation in the recharge area between 2.7 and 4.2x10^{6}m^3/yr.

The well purportedly is completed 350 feet (107m) below ground surface (Gary Overson, personal communication). It is assumed that the mean aquifer depth over the recharge area is 40m, and has a mean porosity of 10%. This suggests an aquifer volume of 35.6x10^{6}m^3. Dividing this volume by 40 years, suggests an annual recharge of 0.89x10^{6}m^3/yr. Comparing this annual recharge to the accumulated precipitation, a suggested total of 21 to 33% of annual precipitation is recharged.

Example #4

The fourth example is from Bonanza spring located on the southeastern side of the Clipper Range (NW,NW1/4 sec22 T7N R15E, Castle Dome, Calif 7.5 USGS Quad). This spring discharges at 640m and has a maximum potential recharge area of about 15.5km^2 (6mi^2) in the Clipper Range. This recharge area has an elevation range between 640 and 1100m. LLNL sampled this spring February 2, 2000. It was discharging at 0.1 cubic foot per second (cfs; 0.17m^3 per minute). The discharge was perennial and supported a maturely vegetated wetland extending at least 1.5km downstream of the spring immersion point.

Assuming a sustained flow of 0.1 cfs annually, we calculate a total annual discharge from Bonanza spring of 71 acre-ft (87,577m^3). The recharge area averages ~900m in elevation. The annual average precipitation rate is calculated to be 160mm/yr. This is a total accumulated precipitation volume of ~2,139,000m^3, or 1734 acre-ft per year. The ratio of spring flow to annual precipitation in the recharge area indicates that the recharge rate for Bonanza spring is 4% of annual precipitation, or 5.5mm/yr.

ENCLOSURE

#6

SECTION 9

Assessing Controls on Diffuse Groundwater Recharge Using Unsaturated Flow Modeling

Submitted to Water Resources Research

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1. ABSTRACT

Understanding climate, vegetation, and soil controls on recharge is essential for estimating potential impacts of climate variability and land use/land cover change on recharge. Recharge controls were evaluated by simulating drainage in 5 m thick profiles using the 1D UNSAT-H code and online climate, vegetation, and soils data. Long-term (1961-1990) simulations were conducted for 13 sites that represent arid to humid climates and different vegetation and soil types using data for Texas, U.S. Point recharge estimates were regionalized at each site using GIS coverages. Simulated mean annual recharge in bare sand is high (51 mm/yr, arid to 709 mm/yr, humid) and represents 23 to 60% of mean annual precipitation (MAP). Vegetation and soil textural variability markedly reduce recharge by factors of 2 to 30. Vegetated, texturally variable soil profiles (most realistic scenario) resulted in 0.2 to 118 mm/yr of recharge (0.1-10% of MAP). Mean annual precipitation explains 80% of the variation in recharge and can be used to map recharge. Local variability in recharge is dominated by the effects of vegetation and soil texture.

2. INTRODUCTION

Understanding controls on the water cycle, such as climate, vegetation, and soils, is important for evaluating the potential impact of climate variability and land use/land cover (LU/LC) change on the water cycle. Land surface models are currently being used on regional scales to assess the relative importance of these influences on the water cycle (Bonan, 1997; Pielke, 1998). These models focus on the evapotranspiration (ET) component of the water cycle and feedback between the land surface and climate and have not been applied to estimate subsurface components of the water cycle. Recharge (addition of water to an aquifer) is a critical component of the water cycle for water resources and as a vector for nutrients and contaminants from the land surface to underlying aquifers. The need to control recharge at regional scales for environmental purposes such as management of water resources and reduction in salinization underscores the importance of understanding fundamental controls on recharge. Examples include removal of brush and riparian vegetation in semiarid regions of Southwestern US to increase recharge, and reforestation in areas of Australia to reduce recharge and associated salinity problems (Weeks, 1987; Welder, 1987; Dugas, 1998; Allison et al., 1990; Dawes et al., 2002).

The basic controls on diffuse groundwater recharge include climate, vegetation, soils, and topography. Diffuse recharge refers to areally distributed recharge derived from precipitation or irrigation and should be distinguished from focused or concentrated recharge in topographic depressions, such as streams, lakes, and playas. Comparison of previous recharge estimates from various studies indicates that recharge is higher in humid versus arid regions; however, most studies focus on recharge in arid regions (Lerner et al., 1990; Robins, 1998). The presence of vegetation markedly reduces recharge in semiarid to arid basins (Gee et al., 1994) and the type of vegetation significantly impacts recharge rates also: higher recharge in areas of annual crops and grasses than in areas of trees and shrubs (Prych, 1998). Replacement of deep-rooted native Eucalyptus trees with shallow-rooted crops in Australia increased recharge by about two orders of magnitude (< 0.1 mm/yr for native mallee vegetation to 5-30 mm/yr for crop/pasture rotations) (Allison et al., 1990). Field and modeling studies have shown that recharge is greater in coarser versus finer textured soils (Cook et al., 1992; Rockhold et al., 1995; Kearns et al., 1998). The influence of topography on recharge is variable. Catchment scale modeling studies indicated that there is very little subsurface lateral movement in some catchments and flow can be treated as 1D (Dawes et al., 1997; Hatton, 1998, Zhang et al., 1999).

Previous studies have evaluated controls on groundwater recharge using field studies or numerical modeling. Kennett-Smith et al. (1994) related variations in recharge to precipitation and clay content using a simple water balance model and field recharge estimates. Multiple regression analysis related variations in field-based recharge estimates primarily to variations in precipitation and also to variations in soil water storage, water table depth, and spring precipitation rate for a 3400 km^2 area in Kansas

(Sophocleous, 1992). Petheram et al. (2002) evaluated impacts of land use on recharge by reviewing previous recharge studies in Australia and correlated recharge to precipitation in areas of annual vegetation and sandy soils (r^2=0.6). However, comparison of recharge rates among the different studies was difficult because of the wide variety of techniques used that represented a range of space and time scales.

Physical, chemical, and modeling approaches can be used to estimate recharge based on surface water, unsaturated zone, and groundwater data (Scanlon et al., 2002a). Numerical modeling is the only tool that can predict recharge and modeling is also extremely useful in isolating and assessing the relative importance of different controls on recharge. Various types of models can be used to simulate recharge, such as land-atmosphere, watershed, unsaturated zone, and groundwater models. Although land-atmosphere codes simulate all the processes required to estimate recharge, including Richards' equation for simulating unsaturated flow and a variety of approaches for simulating evapotranspiration (ET) (Cotton et al., 2003; Dai et al., 2003); these codes have generally not been used to simulate recharge. Watershed models have been used to estimate groundwater recharge (Hatton, 1998; Zhang et al., 1999); however, parameterization of these codes is difficult. Unsaturated zone codes range from simple bucket codes (Hevesi et al., 2002; Hatton, 1998; Lewis and Walker, 2002) to those based on Richards' equation (Braud et al., 1995; Fayer et al., 1996) and some that include plant growth modules (Dawes and Hatton, 1993; Zhang et al., 1996). Simulation studies of recharge range from bare ground (Scanlon and Milly, 1994; Scott et al., 2000) to vegetated systems (Rockhold et al., 1995; Kearns and Hendrickx, 1998). Sensitivity analyses to assess controls on recharge were fairly simplistic ranging from monolithic to simple two layered soil profiles with or without vegetation and different types of vegetation (shrubs/grasses) (Rockhold et al., 1995; Kearns and Hendrickx, 1998). Groundwater model calibration or inversion can also be used to estimate recharge rates; however, model inversion using hydraulic head data only is limited to estimating the ratio of recharge to hydraulic conductivity (Sanford, 2002). Such recharge estimates are generally not considered highly reliable because hydraulic conductivity can vary over several orders of magnitude. More reliable recharge estimation requires information on water fluxes or ages in addition to hydraulic head to calibrate the model (Sanford, 2002).

Primary difficulties with modeling recharge are data requirements and model parameterization. Online data sources have made recharge simulations much more feasible. Weather generators, such as GEM (Generation of weather Elements for Multiple applications, include databases of meteorological stations and can generate data for other regions (Hanson et al., 1994; Richardson, 2000). Geographic Information Systems (GIS) distributions of soils are provided by State Soil Geographic (STATSGO) database (1:250,000 scale) and Soil Survey Geographic (SSURGO) database (1:24,000 scale). Pedotransfer functions are available to transfer soil texture information into water retention and hydraulic properties required for modeling (Schaap et al., 2001). Vegetation distribution and land use (National Land Cover Data) can also be obtained from online sources (McMahon et al., 1984; Vogelmann et al., 2001).

The purpose of this study was to determine the relative importance of different controls on diffuse groundwater recharge using unsaturated one-dimensional flow models of recharge for sites representing a range of climate (arid-humid), vegetation (shrub, grass, forest, crops), and soil (fine to coarse grained, monolithic and layered) conditions based on data from Texas. This study focuses on long-term (30 yr), areally averaged recharge rates that are appropriate for assessing water resources and evaluating aquifer vulnerability to nutrient loading. Unique aspects of the study are (1) range of climate, vegetation, and soil conditions examined, (2) use of online and literature data sources for input and parameterization of the models, (3) combination of 1 D modeling and GIS to develop areally averaged recharge estimates, (4) length of simulations (1961-1990), and (5) comparison with field-based estimates.

3. MATERIALS AND METHODS

3.1 Study Area Description: Climate, Soils, and Vegetation

The broad study area is the state of Texas (~700,000 km^2) (Fig. 1). Thirteen study sites, representing a variety of climate, vegetation, and soil types were used in this study to simulate the water balance for a 30 yr period (1961-1990). Sites were also located to represent the major porous media aquifers in the state (Fig. 1, Table 1). Each study site represents a 1 or 2 county area within an aquifer (1,152-3,042 km^2) with the exception of site 2 (entire outcrop of Cenozoic Pecos Alluvium Aquifer: 14980 km^2). The topography of the sites is generally flat with average slopes $\leq 0.5\%$ in the High Plains and Gulf Coast regions and slightly higher slopes in the remaining sites ($\leq 1.3\%$). Long-term (1961-1990) mean annual precipitation (MAP) ranges from 224 mm/yr in the west to 1184 mm/yr in the east. Annual precipitation at individual meteorological stations ranged from 110 mm (site 1, El Paso, 1969) to 1783 mm (site 13, Houston, 1973). Summer precipitation (Jun-Aug) is dominant throughout much of the area, particularly in the western (43%) and northern (33 to 48%) sites (Fig. 2). Spring precipitation is dominant in the central sites (29 to 33%), whereas fall precipitation is dominant in the southeastern sites (28-39%). Precipitation is fairly uniformly distributed in the more humid regions in the east. Winter precipitation (Dec-Feb) is generally low throughout most of the state (8-16%), with the exception of the humid east (21%). The coefficient of variation (CV) in annual precipitation is greatest in semiarid regions in the west (0.35), and less throughout the rest of the area (CV: 0.21-0.24) (Figure 3, Table 2). Vegetation ranges from predominantly shrubs and grasses in the west, shrub/forest to forest/shrub in central area, and forest and forest/shrub in the east (Fig. 4). Cropland areas dominate much of the northern and southeastern regions. Variations in clay content in the upper 1.5 to 2 m soil profile depths based on STATSGO data generally follow the distribution of underlying geologic units, e.g. high clay contents in the central region of the Southern High Plains (site 5) corresponding to the Blackwater Draw Formation and high clay contents in the northern and central portions of the Gulf Coast (sites 12 and 13) corresponding to the Beaumont Formation (Fig. 5).

3.2 Model Description

Unsaturated flow modeling was used to simulate drainage below the root zone, which is equated to groundwater recharge and assumes that climate and LU/LC remain constant over timescales required for water to move from the root zone to the water table. The UNSAT-H code (Version 3.0; Fayer, 2000) was chosen for the simulations because previous code comparison studies showed that water balance simulations based on UNSAT-H compared favorably with field data (Scanlon et al., 2002b). UNSAT-H is a 1D, finite difference code that simulates nonisothermal liquid flow and vapor diffusion in response to meteorological forcing. The simulations focus on the water balance:

$$D = P - ET - R_0 - \Delta S \qquad (1)$$

where D is deep drainage below the root zone, P is precipitation, ET is evapotranspiration, R_0 is surface runoff, and ΔS is change in water storage. UNSAT-H simulates subsurface water flow using Richards' equation:

$$\frac{\partial \theta}{\partial t} = -\frac{\partial q}{\partial z} = \frac{\partial}{\partial z}\left((K(\theta)\frac{\partial H}{\partial z} \right) - S = \frac{\partial}{\partial z}\left((K(\theta)\frac{\partial h}{\partial z} - K(\theta) \right) - S(z,t) \qquad (2)$$

where θ is volumetric water content, q is water flux, K is hydraulic conductivity, H is hydraulic head, h is matric potential head, and S is a sink term used to describe the removal of water by plants. UNSAT-H includes multiple analytical functions for water retention and unsaturated hydraulic conductivity.

The upper atmospheric boundary condition is simulated as a system dependent boundary condition that changes from a prescribed head to a prescribed flux depending on climate and subsurface conditions. If the applied flux (precipitation or evapotranspiration) is $\leq$ the potential flux and the matric potential head at the surface is between 0 and a prespecified dry value (h_{dry}), then the potential flux, which is controlled by external conditions, applies. Runoff is simulated implicitly by UNSAT-H. If the precipitation rate exceeds the infiltration capacity of the soil, excess water runs off (infiltration excess or Hortonian runoff). If the matric potential head at the surface reaches 0, the soil becomes saturated, a constant head boundary condition applies (h=0), and excess water runs off (saturation excess flow, Dunne runoff). If the soil surface becomes too dry ($h \leq h_{dry}$), a constant head boundary condition applies ($h=h_{dry}$) and evaporation or evapotranspiration is controlled by the rate at which water can be transmitted to the surface. Ponding is not simulated with this code. Plant water uptake is simulated according to the approach proposed by Feddes et al. (1978) that partitions PET into potential evaporation (PE) and potential transpiration (PT) using an empirical equation developed by Ritchie and Burnet (1971) which distributes PT over the root zone based on depth variations in root density, and reduces this PT to actual transpiration based on matric potential head (Fayer, 2000).

3.3 Model Application

The water balance for a 30 yr period (1961-1990) was simulated for 13 study sites. Input data requirements for the model include meteorologic forcing, vegetation

parameters, hydraulic parameters for different soil types, and initial conditions. To assess the relative importance of different controls on groundwater recharge, four different scenarios were used:

1. nonvegetated, monolithic sand
2. nonvegetated, texturally-variable soil
3. vegetated, monolithic sand
4. vegetated, texturally-variable soil

The simplest simulations of nonvegetated, monolithic sand were used to provide an upper bound on recharge rates. Complex texturally-variable soil profiles were simulated without vegetation to evaluate the impact of soil textural variability on recharge. Vegetation was added to the monolithic and texturally-variable soil profiles to determine its impact on simulated recharge. The most realistic scenario is represented by vegetated, texturally variable soils.

A soil-profile depth of 5 m was chosen for the simulations because it is deeper than the root zone depths of the vegetation used. In addition, soil textural information is only available for the upper 2 m from STATSGO and SSURGO. Sensitivity of simulated recharge to profile depth was evaluated. In monolithic profiles, nodal spacing ranged from 2 mm at the top and base of the profile and increased by a factor of ~1.2 to a maximum value of 230 mm within the profile. In layered soil profiles, nodal spacing was also reduced near textural interfaces to a value of ~20 mm. Initial conditions were arbitrarily set at a matric-potential head of -3 m for higher precipitation sites (6-13) and -10 m for all other sites. The impact of initial conditions on simulation results was evaluated by reinitializing the simulations multiple times with the final conditions of each run; however, rerunning simulations once was found to be sufficient for minimizing the impact of initial conditions.

Meteorological data for 10 stations were obtained from the database in the GEM code (Hanson et al., 1994). Some station data were used to simulate recharge in more than one site (Midland station–sites 2 and 3; Fort Worth station–sites 9-11). The 1961-1990 period was chosen because of availability of solar radiation for potential evapotranspiration calculations from the National Solar Radiation Data Base (National Renewable Energy Laboratory, Golden, Colorado; 1992). Meteorologic input to the model included daily precipitation, daily average dew point temperature, wind speed and cloud cover, total daily solar radiation, and minimum and maximum daily temperature. Daily precipitation was applied at a prespecified default intensity of 10 mm/hr and ET is not simulated during this time. Previous code comparisons showed that the approach used in codes to simulate precipitation and evapotranspiration when daily precipitation is used as input can have a large impact on simulated recharge and the UNSAT-H approach adequately simulates measured data (Scanlon et al., 2002b). A modified Penman-Monteith equation was used to calculate PET (Doorenbos and Pruitt, 1977). Parameter h_{dry} was set to -1000 m. A unit gradient lower boundary condition was used that corresponds to free drainage or gravitational flow and is most appropriate for simulating unimpeded recharge.

The distribution of vegetation types for each of the modeled sites was obtained from a GIS coverage of vegetation in Texas (McMahan et al., 1984) (Figs. 4, 6). Vegetation parameters required for UNSAT-H include percent bare area, root-length density (RLD), time series of rooting depth and leaf area index (LAI), and planting and harvesting dates for crops. These parameters were generally obtained from the literature (App. A[1]). Time series for root growth and LAI were specified on particular days of the year and linearly interpolated. Root growth was simulated for crops only, other plant types were perennial. The RLD function is based on the assumption that the normalized total root biomass is directly related to RLD (ρ_{rL}) and can be related to the depth below the surface (z) by:

$$\rho_{rL} = a\exp(-bz) + c \qquad (3)$$

where a, b, and c are coefficients that optimize the fit to the normalized biomass data. Recharge for areas with more than one vegetation type, such as trees with grasses, was estimated by simulating the different vegetation types separately and combining the results. The dominant vegetation types that represented ~70-80% of the area of each site were simulated.

Soil profiles for the simulations ranged from monolithic sand to texturally variable profiles. Hydraulic properties for the sand were obtained from the UNSODA database (UNSODA 4650: K_s: 5.87 m/day; θ_s: 0.38; θ_r: 0; α: 0.0503 1/m; n: 1.7736; Leij et al., 1996). SSURGO version 2 data (USDA, 1994) were used to provide information for texturally variable soil profiles for all sites but was unavailable for site 2 where STATSGO data (USDA, 1995) were used for the entire (multi-county) outcrop area of the aquifer. Pedotransfer functions were used to determine soil hydraulic properties. Rosetta software uses neural network programming and a database of measured texture, water retention, and saturated hydraulic conductivity samples to provide estimates of the van Genuchten water-retention parameters and saturated hydraulic conductivity for input to unsaturated flow models (Schaap et al, 2001). Only texture and bulk density information was available from the STATSGO database for input to the Rosetta program. Soil layer texture, bulk density, and volumetric water content at -3 and -150 m head were available from the SSURGO version 2 database for input to Rosetta. The number of dominant soil profiles that represented ~80% of the area of each site ranged from 6 to 29. Profiles with similar recharge results were grouped into categories at each site, which resulted in 3 to 7 representative profiles for each site.

The simulated recharge results are represented by a single temporal (30 yr) and spatial average recharge value for each site using GIS analysis to spatially weight simulated recharge rates for each vegetation type, soil type, or combination of vegetation and soil types (Table 2). A total of 460 simulations were conducted for the final analysis. For the monolithic profile simulations, models were developed for each of the 10 meteorological stations resulting in 10 representative recharge values. For the vegetated and texturally variable soil profile simulations, 13 recharge values representative of each of the study sites were determined. Recharge rates for each site (30 yr, spatially weighted

[1] Supporting material is available via Web browser or via Anonymous FTP from ftp://ftp.agu.org/apend/" (Username = "anonymous", Password = "guest").

average) was plotted versus long-term (30 yr) mean annual precipitation (MAP) and equations were fit to the results for each of the four modeling scenarios (i.e., non-vegetated monolithic and texturally variable soil profiles, and vegetated monolithic and texturally variable soil profiles) (Fig. 7). Power law equations were used as they resulted in higher correlation coefficients and lower residual standard deviations than linear or log linear equations (Table 3). Finally, the power law equations were used to generate continuous statewide recharge rate maps for each of the modeling scenarios based on the distribution of MAP. Though shown for the entire state, the results should only be applied to the outcrop areas of the porous media aquifers shown.

Sensitivity of recharge to climate, vegetation, and soils was evaluated in the four different scenarios considered, which isolated the impact of each of these parameters. Additional sensitivity analyses were conducted to evaluate variations in vegetation parameters, initial conditions, PET, depth of soil profile. Vegetation parameters evaluated included percent bare area, leaf area index, root depth, and root-length density. Each parameter was increased and decreased by 50 percent, with the exception of percent bare area, which is 0 for the base case and was increased to 25 and 50%, and profile depth which was increased from 5 to 10 m in the sensitivity analysis. Sensitivity analyses were conducted using data from site 6.

4. RESULTS AND DISCUSSION

Simulation results are represented for the four basic scenarios to assess the relative importance of climate, vegetation, and soils in controlling recharge. Final mass balance errors were less than 5% of final recharge and less than 0.5 mm/yr.

4.1 Nonvegetated, Monolithic Sand Simulations

Simulated mean (30 yr) annual recharge for bare sand is high and ranges from 51 mm/yr in the arid west to 709 mm/yr in the more humid east, representing 23 to 60% of mean (30 yr) annual precipitation (Table 2). Variations in mean annual recharge can be explained entirely by variations in mean annual precipitation. Recharge increased with precipitation (r^2=1.0; Fig. 7, Table 2). Lower correlations between mean annual recharge and summer precipitation (r^2=0.66) relative to precipitation during the other seasons (r^2=0.83-0.96 for spring, fall, and winter) was attributed to higher evaporation during the summer (Figs. 2 and 8). These recharge estimates provide an upper bound on actual recharge rates because vegetation and soil textural variability were not included and simulated runoff was zero whereas actual runoff estimates based on state wide water balance ranged from 0 mm/yr in the west to 415 mm/yr in the east (Reed et al., 1997). Lack of simulated runoff was attributed to the high saturated hydraulic conductivity of the sand (0.24 m/hr) relative to the prespecified precipitation intensity (0.01 m/hr). Temporal variability in annual recharge is similar throughout the state (CV: 0.16-0.24) and is less than that of precipitation (Table 2). Potential ET is much greater than simulated actual ET; the PET/AET ratio decreased from 12.1 in the west (site 1) to 2.9 in the east (site 13) (Table 2). In arid regions most infiltrated water is returned to the

atmosphere through evaporation, as shown by the tracking of precipitation and evaporation (Fig. 9) and high correlation between evaporation and precipitation at site 1 (r^2=0.83). Annual recharge is not directly correlated with annual precipitation (r^2=0.03) because there is a lag between elevated precipitation and recharge. In contrast, in more humid settings evaporation and precipitation are not as highly correlated (r^2=0.66, site 13). There is little lag between high precipitation and recharge as shown by the strong correlation between annual precipitation and recharge (r^2=0.90, site 13).

4.2 Nonvegetated, Texturally Variable Soil Simulations

Simulated mean (30 yr) annual areally averaged recharge ranges from 16 mm/yr in the north to 230 mm/yr in the southeast for texturally variable soil profiles, representing 3 to 29% of MAP (Fig. 7, Table 2). These recharge rates are 2 to 11 times lower than those based on monolithic sand profiles indicating the importance of soil textural variability in controlling recharge. The lower recharge rates may reflect finer textured soils or may be related to reductions in recharge caused by profile layering, both fine over coarse (capillary barrier effect) and coarse over fine layering. Reductions in recharge in the texturally-variable soil simulations correspond to increased runoff, evaporation, or both. Approximately 60% of the variation in recharge can be explained by variations in precipitation (r^2=0.62). Multiple linear regression using log-log data showed that including clay content with precipitation could explain 80% of the variation in recharge. Recharge varied over 1 to 2 orders of magnitude locally, within each site because of textural variability among the soil profiles.

Variations in simulated mean (30 yr) annual runoff generally reflect differences in climate and texture among sites. Simulated runoff was positively correlated with mean clay content (r^2=0.57) and negatively correlated with mean sand content (r^2=-0.49). Sandy areas, particularly sites 1, 2, 3, and 7, have low runoff and generally correspond to areas of low or moderate precipitation. Most sites with clay rich soils have higher runoff and generally overly fine grained geologic units. Simulated recharge rates in clay-rich soils may not accurately reflect actual recharge rates if preferential flow occurs in these settings because this process is not included in the simulations.

4.3 Vegetated, Monolithic Sand Simulations

To assess the impact of vegetation without the influence of soil textural variability, simulations of recharge were conducted in vegetated, monolithic sands (Table 2). Simulated mean (30 yr) annual recharge ranges from 2 mm/yr in the arid west to 369 mm/yr in the humid east, representing 1 to 31% of MAP. MAP explains 85% of the variance in simulated recharge (Fig. 7). Vegetation markedly reduces recharge and increases ET by factors of 2 to 30 relative to recharge for nonvegetated simulations. Simulated runoff was 0 for nonvegetated and vegetated simulations. The type of vegetation also affects simulated recharge, as seen in the 1 to 2 orders of magnitude range in simulated recharge rates for different vegetation types within a study site. In general, lower recharge rates in areas with trees relative to grasses can be attributed to greater

rooting depth of trees (≤ 4.3 m) relative to grasses (≤ 1 m). Crops also differed in their recharge rates: e.g. factor of 4 lower recharge beneath cotton (maximum rooting depth 2.1 m) relative to sorghum (maximum rooting depth 1.5 m), in site 4). Shrubs were generally more effective than crops in reducing recharge because of greater root zone depth and longer growing season.

4.4 Vegetated, Texturally Variable Soil Simulations

The texturally variable soils with vegetation is the most realistic representation of actual conditions and should provide the most reliable recharge estimates for the different sites. Simulated mean (30 yr) annual, areally averaged recharge ranges from 0.2 mm/yr in the arid west to 118 mm/yr in the humid east, representing 0.1 to 10% of precipitation (Fig. 7, Table 2). Approximately 80% of the variability in recharge rates among sites can be explained by variability in MAP. The relationship between recharge and precipitation was used to map recharge throughout the entire study area (Fig. 10).

Simulated recharge for vegetated, texturally-variable soils was much less than that for nonvegetated, texturally-variable soils. Reduction factors were greater in more arid sites in the west (12-423) relative to more humid sites in the east (6-92) and reflects the enhanced ability of vegetation to reduce recharge in more water-limited regions (Table 2). Local variability in simulated recharge within sites was generally within an order of magnitude and reflects variability due to differences in vegetation and soil texture.

Simulated mean (30 yr) annual runoff was generally consistent with previous mean annual runoff estimates at many sites based on measured stream gage data (1961-1990) used to develop a statewide water balance (Reed et al., 1997) (Table 4). Discrepancies between the two estimates at other sites cannot readily be explained with the exception of sites 4 and 5 in the Southern High Plains where overestimation of runoff may be attributed to predominantly internal drainage to ephemeral lakes or playas and little runoff to gauged stream networks. Runoff is one of the most difficult parameters to simulate because it depends on accurate representation of rainfall intensity and hydraulic conductivity of surficial sediments that may be crusted as shown by detailed comparisons of simulated and measured runoff at a controlled field experiment (Scanlon et al., 2002b).

The relative controls of different vegetation types in vegetated, texturally-variable soil simulations are similar to those for vegetated monolithic sands: lower recharge in deep rooted trees relative to shallow rooted grasses; shrubs relative to crops, and cotton relative to sorghum. For example, in site 9, simulated recharge beneath trees was zero whereas simulated recharge beneath grasses ranged from 1 to 156 mm/yr for different soils. Relative amounts of evaporation and transpiration varied with vegetation type and soil texture. Transpiration was much greater than evaporation for trees irrespective of texture. Evaporation was higher than transpiration in finer textured soils than in coarser textured soils irrespective of vegetation type, which is attributed to finer textured soils retaining more water near the soil surface longer allowing greater evaporation.

4.5 Sensitivity Analyses

Sensitivity analyses were conducted for site 6 because it represents average climate and soil conditions in the study area. Simulated recharge was sensitive to varying vegetation parameters. Increasing percent bare area from 0 to 50% increased recharge by up to a factor of 8 (Table 5). Simulated recharge was inversely related to root depth because decreasing root depth allows water to drain more readily below the root zone. Decreasing root depth increased recharge by factors of 2 to 5 whereas increasing root depth decreased recharge by factors of 0.2 to 0.5. Simulated recharge was more sensitive to decreasing LAI than increasing LAI. Decreasing LAI by 50% almost doubled recharge while increasing LAI by 50% decreased recharge by 20%. The models were insensitive to variations in root length density.

Decreasing PET increased recharge by factors ranging from 4 in coarse grained soils to 38 in fine grained soils and was balanced by a reduction in ET whereas increasing PET had the opposite effect. The model was insensitive to variations in initial conditions. Increasing profile depth from 5 to 10 m decreased recharge in coarse-grained soils by a factor of 0.9 and increased recharge by a factor of 1.2 in the fine-grained soil, which may be an artifact of drainage of initial water in the profile. Model equilibration times are greater for more arid settings and more clay-rich soils. Therefore, final recharge estimates in these settings may represent an upper bound on actual recharge rates.

4.6 Comparison of Simulated Recharge Estimates with those Based on Other Techniques

Simulated recharge rates from this study were compared with those based on earlier studies (Table 6). Previous field and modeling investigations in the Chihuahuan Desert in west Texas indicated that there is no recharge in interdrainage settings (Scanlon et al., 1999) which is generally consistent with the low (0.2 mm/yr) simulated recharge in this study (Table 2). Bulge shaped chloride profiles and upward matric potential gradients indicate that this system has been drying out for the last 10,000 to 15,000 yr since the Pleistocene (Scanlon et al., 2003a).

In the Southern High Plains, it is difficult to compare simulated recharge rates from this study, which represent diffuse recharge in interdrainage settings, with previous recharge estimates from groundwater data because most recharge in this region is focused beneath playas. Therefore, simulated recharge at sites in the Southern High Plains (4 and 5) (0.4-0.9 mm/yr) is less than recharge estimates based on the chloride mass balance (CMB) approach applied to groundwater (11 mm/yr; Wood & Sanford, 1995), as expected. Field studies indicate that there is no recharge in natural ecosystems in interplaya settings as shown by chloride bulges and upward matric potential gradients (Wood and Sanford, 1995; Scanlon and Goldsmith, 1997, Dennehy et al., 2004). Recharge estimates based on chloride profiles from nonirrigated cultivated settings in the southern part of the Southern High Plains range from 4 to 28 mm/yr (Scanlon et al., 2003b). Simulated recharge rates at sites 3 and 4 (0.9-1.5 mm/yr) fall within the range of values for natural and cultivated regions and may underestimate actual recharge because

the effect of cultivation on hydraulic properties of surficial sediments was not included in the simulations.

Simulated recharge in site 6 (5.6 mm/yr) is within the lower range of field based estimates using the CMB approach applied to the unsaturated zone (UZ) in natural and nonirrigated cultivated regions (5-30 mm/yr) (Scanlon et al., 2003b). The higher values from the field studies may be attributed to restriction of field sites to a large sand dune setting whereas the spatially averaged value from this modeling study also includes finer-grained soils found in other regions.

Simulated recharge at site 8 (10 mm/yr) is within the range of field-based recharge estimates based on the chloride mass balance (CMB) approach applied to the unsaturated zone and groundwater (5-20 mm/yr; Dutton et al., 2003). Recharge estimates based on the CMB approach applied to groundwater for site 11 range from 43 to 71mm/yr and are slightly higher than that simulated (35 mm/yr). The discrepancy may be attributed to the bias toward high-permeability units in field-based estimates.

Although the number of comparisons between simulated and field-based recharge estimates is limited, simulated recharge rates in this study are generally consistent with those based on previous field studies, and discrepancies can generally be explained by inclusion or exclusion of different types of recharge (e.g., focused versus diffuse recharge in the Southern High Plains) and focusing on different zones (e.g., high permeability versus low permeability units).

4.7 Recommendations for Future Studies

This study represents a relatively simple approach for estimating recharge using a 1 D unsaturated flow model and online data. Future studies can expand this modeling analysis to improve data inputs to the models and evaluate additional controls on recharge. Future simulations should consider using actual precipitation intensity where data are available in lieu of the default 0.01 m/hr used in this study. This study did not simulate recharge in irrigated areas because of uncertainties in irrigation applications; however, future studies should attempt to develop inputs for irrigation and simulate recharge in irrigated regions.

Vegetation dynamics should be incorporated into the simulations that would allow two-way coupling between vegetation growth and soil moisture variability related to climate. The current simulations prescribe vegetation input which precludes vegetation response to variability in soil moisture and precipitation. Including plant growth in the recharge model should provide more realistic simulations of recharge, particularly in semiarid-arid regions where vegetation productivity varies in response to changes in precipitation and soil moisture as shown by field measurements and remote sensing data (Jolly et al., 2003; Nemani et al., 2003). Dynamic vegetation is simulated in land atmosphere modeling by linking physical flow codes with ecosystem codes (Foley et al., 1998; Bonan et al. 2003) to evaluate long-term effects of vegetation dynamics. Remote sensing provides valuable information on vegetation parameters over time at 30 m (LandSat TM) to 1.1 km (MODIS) resolution depending on the satellite imagery used. Satellite data may be used to locate irrigation systems, evaluate crop rotations, and

determine when fields are fallow. Percent bare area can be estimated from fractional vegetation coverage using satellite data such as AVHRR or MODIS. Information on leaf area index is available from atmospherically corrected normalized difference vegetation index (NDVI) (Myneni et. al., 1997). It is more difficult to obtain information on rooting depths; however, existing databases and field monitoring data can provide information on depth of root activity (Scanlon et al., in press).

Future studies should evaluate pedotransfer functions from different sources (Wosten et al., 2001; Romano and Paladino, 2002). The importance of crusts in controlling partitioning of water at the land surface should also be evaluated as well as the effects of land use on hydraulic parameters. Cultivation may markedly alter hydraulic conductivity of surficial sediments that could greatly impact the partitioning of precipitation among runoff, infiltration, and ET; however, field measurements of hydraulic conductivity in cultivated regions are limited. This study focused on diffuse recharge in porous media systems; however, finer textured soils found in different areas are subject to desiccation and cracking resulting in preferential flow. Codes being modified to simulate preferential flow (Simunek et al., 2003) should be tested in areas of fine textured soils to evaluate the potential impact of preferential flow on simulated recharge.

4.8 Implications for Water Resources and Nutrient Transport

Reliable recharge estimates are critical for evaluation of and optimal management of water resources. Long-term average recharge rates are beneficial for groundwater managers because management plans are generally developed for decadal time scales. The relationship between precipitation and recharge developed in this study for vegetated, texturally-variable soils was used to map spatial variability of recharge for the groundwater model of the Carrizo-Wilcox aquifer in Texas (Kelley et al., 2004). Scaling factors were developed for the groundwater model that varied these recharge rates with topography and subsurface geology with high recharge in upland areas and above more permeable geologic units similar to the B value discussed in Hatton (1998).

The understanding of controls on groundwater recharge developed in this study will allow water-resource managers to assess potential impacts of climate variability and land use/land cover (LU/LC) change on groundwater availability. The relationship between spatial variability in precipitation and recharge developed in this study may be used to address potential impacts of climate variability on recharge by using space as a proxy for time. Many groundwater models use temporal variability in precipitation as a direct indicator of variability in recharge; however, the buffering effect of the unsaturated zone should be considered because it dampens and lags the impact of short term climate variability on recharge. The effect of vegetation on simulated recharge can be used to provide preliminary estimates of potential impacts of removing invasive woody species in many areas of Texas. The state is currently investing millions of dollars in this program to increase water availability.

The recharge estimates developed in this study may be useful in assessing aquifer vulnerability to nonpoint source contaminants such as nutrients (e.g. nitrates). High

recharge rates may result in aquifers being more or less susceptible to contamination. High recharge rates may reduce aquifer vulnerability by diluting contaminants as seen in nitrate contamination in New Jersey (Nolan et al., 2003) where areas of high recharge resulted in lower nitrate levels. Inverse relationships between precipitation and nitrate contamination in Texas also suggest that high recharge causes dilution (Evans and Maidment, 1995).

5. CONCLUSIONS

1. Unsaturated zone modeling using online data is a useful approach for simulating diffuse recharge in porous media systems
2. Climate, vegetation, and soils each exert controls on groundwater recharge
   a. High simulated long-term (30 yr) mean annual recharge (51-709 mm/yr) in nonvegetated sandy profiles, represents 23 to 60% of mean annual precipitation and provide an upper bound on actual recharge
   b. Soil textural variability controls recharge as shown by the large reduction by factors of 2 to 11 in simulated recharge for nonvegetated, texturally variable soils relative to those in monolithic sands.
   c. The presence and type of vegetation controls recharge as shown by the reduction in recharge in vegetated relative to that in nonvegetated monolithic and texturally variable soils (factors of 2-30). Reductions in recharge due to vegetation were greater in arid/semiarid sites relative to the more humid sites.
3. The most realistic long-term (30 yr) recharge estimates based on vegetated, texturally variable soils ranged from 0.2 to 118 mm/yr, representing 0.1 to 10% of long-term precipitation.
4. Approximately 80% of the variability in simulated recharge can be explained by variability in MAP in vegetated, layered soil profiles. MAP can be used as a predictor of mean annual recharge.
5. Simulated long-term spatially averaged recharge rates generally compared favorably with recharge estimates based on previous field studies.
6. Simulated long-term (30 yr) spatially averaged runoff was generally within the range of estimates based on gage data in state-wide water balance modeling for most of the sites. Discrepancies in the Southern High Plains can be explained by internal drainage to playas.
7. Future modeling analyses should include improvements in model input from satellite data; model processes, particularly vegetation dynamics; and data for comparison with model output
8. Unsaturated zone modeling provides a valuable tool to isolate controls on groundwater recharge. Understanding these controls can be used to assess potential impacts of climate variability and land use/land cover change on groundwater recharge.

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REFERENCES

Allison, G. B., P. G. Cook, S. R. Barnett, G. R. Walker, I. D. Jolly, and M. W. Hughes. 1990. Land clearance and river salinisation in the western Murray Basin, Australia. J. Hydrol. **119**:1-20.

Arnold, E. 1992. World Atlas of Desertification. UNEP's Desertification Control Programme Activity Centre, Global Environment Monitoring System, and the Global Resource Information Database. London (UK).

Bonan, G. B. 1997. Effects of land use on the climate of the United States. Climatic Change **37**:449-486.

Bonan, G. B., S. Levis, S. Sitch, M. Vertenstein, and K. W. Oleson. 2003. A dynamic global vegetation model for use with climate models: concepts and description of simulated vegetation dynamics. Global Change Biology **9**:1543-1566.

Braud, I., A. C. Dantas-Antonino, M. Vauclin, J. L. Thony, and P. Ruelle. 1995. A simple soil-plant-atmosphere transfer model (SiSPAT) development and field verification. J. Hydrol. **166**:213-250.

Cook, P. G., and S. Kilty. 1992. A helicopter-borne electromagnetic survey to delineate groundwater recharge rates. Water Resour. Res. **28**:2953-2961.

Cotton, W. R., R. A. Pielke, R. L. Walko, G. E. Liston, C. J. Tremback, H. Jiang, R. L. McAnelly, J. Y. Harrington, M. E. Nicholls, G. G. Carrio, and J. P. McFadden. 2003. RAMS 2001: Current status and future directions. Meteorol. and Atmos. Phys. **82**:5-29.

Dai, Y. X., X. Zeng, R. E. Dickinson, I. Baker, G. Bonan, M. Bosilovich, S. Denning, P. Dirmeyer, P. Houser, G. Niu, K. Oleson, A. Schlosser, and Z.-L. Yang. 2003. The Common Land Model (CLM). Bull. Amer. Meteor. Soc. **84**:1013-1023.

Dawes, W. R., M. Gilfedder, M. Stauffacher, J. Coram, S. Hajkowicz, G. R. Walker, and M. H. Young. 2002. Assessing the viability of recharge reduction for dryland salinity control: Wanilla, Eyre Peninsula. Aust. J. Soil Res. **40**:1407-1424.

Dawes, W. R., and T. J. Hatton, TOPOG_IRM, 1, Model description, Tech. Memo. 93/5, Commonwealth Sci. and IND. Res. Organ., Div. of Water Resour., Canberra, A. C. T., Aust., 1993.

Dawes, W. R., L. Zhang, T. J. Hatton, P. H. Reece, G. T. H. Beale, and I. Packer. 1997. Application of a distributed parameter ecohydrological model (TOPOG_IRM) to a small cropping rotation catchment. J. Hydrol. **191**:67-89.

Dennehy, K. F., B. W. Bruce, and C. A. McMahon. 2004. Evaluation of recharge beneath irrigated and natural settings in the Southern High Plains. USGS Water Resour. Inv. Rept.

Doorenbos, J., and W. O. Pruitt. 1977. Guidelines for predicting crop water requirements. FAO Irrigation and Drainage Paper No. 24, 2nd ed., Food and Agriculture Organization of the United Nations, Rome, Italy:144 p.

Dugas, W. A., R. A. Hicks, and P. Wright. 1998. Effect of removal of Juniperus ashei on evapotranspiration and runoff in the Seco Creek watershed. Water Resour. Res. **34**:1499-1506.

Dutton, A. R., B. Harden, J. P. Nicot, and D. O'Rourke. 2003. Groundwater availability model for the central part of the Carrizo-Wilcox aquifer in Texas. Contract Rept. prepared for the Texas Water Development Board, variably paginated.

Evans, T. A., and D. R. Maidment. 1995. A spatial and statistical assessment of the vulnerability of Texas groundwater to nitrate contamination. Center for Res. Water Resour., Tech. Rept 260, 259 p.

Fayer, M. J. 2000. UNSAT-H Version 3.0: Unsaturated Soil Water and Heat Flow Model, Theory, User Manual, and Examples. Pacific Northwest National Laboratory 13249: variously paginated.

Fayer, M. J., G. W. Gee, M. L. Rockhold, M. D. Freshley, and T. B. Walters. 1996. Estimating recharge rates for a groundwater model using a GIS. J. Environ. Qual. **25**:510-518.

Feddes, R. A., P. J. Kowalik, and H. Zaradny. 1978. Simulation of field water use and crop yield. Simulation Monographs, PUDOC, Wageningen, The Netherlands:189 p.

Foley, J. A., S. Levis, I. C. Prentice, D. Pollard, and T. S. L. 1998. Coupling dynamic models of climate and vegetation. Global Change Biology **4**:561-579.

Gee, G. W., P. J. Wierenga, B. J. Andraski, M. H. Young, M. J. Fayer, and M. L. Rockhold. 1994. Variations in water balance and recharge potential at three western desert sites. Soil Sci. Soc. Am. J. **58**:63-71.

Hanson, C. L., K. A. Cumming, D. A. Woolhiser, and C. W. Richardson. 1994. Microcomputer program for daily weather simulation. U.S. Dept. Agric., Agric. Res. Svc. Pub. No. ARS-114, 38 pp.

Hatton, T. J. 1998. Catchment Scale Recharge Modeling. Part 4 of The Basics of Recharge and Discharge. CSIRO, Collingwood, Victoria.

Hevesi, J. A., A. L. Flint, and L. E. Flint. 2002. Preliminary estimates of spatially distributed net infiltration and recharge for the Death Valley Region, Nevada-California. U.S. Geol. Surv. Water Resour. Inv. Rept., 02-4010, 36 p.

Jolly, W. M., and S. W. Running. 2003. Effects of precipitation and soil water potential on drought deciduous phenology in the Kalahari. Global Change Biology **doi: 10.1046/j.1529-8817.2003.00701.x.**

Kearns, A. K., and J. M. H. Hendrickx. 1998. Temporal variability of diffuse groundwater recharge in New Mexico. New Mexico Water Resour. Res. Inst. Tech.Compl. Rept. No. 309:43.

Kelley, V., N. Deeds, and J. P. Nicot. 2004. Groundwater availability model of the Queen City Sparta Aquifer. Contract Rept. prepared for the Texas Water Development Board, variably paginated.

Kennett-Smith, A., P. G. Cook, and G. R. Walker. 1994. Factors affecting groundwater recharge following clearing in the south western Murray Basin. J. of Hydrol. **154**:85-105.

Leij, F. J., W. J. Alves, M. T. van Genuchten, and J. R. Williams. 1996. The UNSODA unsaturated soil hydraulic database, User's Manual. Version 1.0. EPA/600/R-96/095, National Risk Management Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio.

Lerner, D. N., A. S. Issar, and I. Simmers. 1990. Groundwater Recharge. Intl Assoc. Hydrogeologists.

Lewis, M. F., and G. R. Walker. 2002. Assessing the potential for episodic recharge in south-western Australia using rainfall data. Hydrogeol. J. **10**:229-237.

McMahon, C. A., R. G. Frye, and K. L. Brown. 1984. The vegetation types of Texas including cropland. Texas Parks and Wildlife, 40 p.

Myneni, R. B., R. R. Nemani, and S. W. Running. 1997. Estimation of global leaf area index and absorbed PAR using radiative transfer models. IEEE Trans. Geosci. Remote Sens. **35**:1380-1393.

Nemani, R. R., C. D. Keeling, H. Hashimoto, W. M. Jolly, S. C. Piper, C. J. Tucker, R. B. Myneni, and S. W. Running. 2003. Climate-driven increases in global terrestrial net primary production from 1982 to 1999. Science **300**:1560-1563.

Nolan, B. T., A. L. Baehr, and L. J. Kauffman. 2003. Spatial Variability of Groundwater Recharge and its Effect on Shallow Groundwater Quality in Southern New Jersey. Vadose Zone J. **2**:677-691.

Petheram, C., L. Zhang, G. R. Walker, and R. Grayson. 2000. Towards a framework for predicting impacts of land-use on recharge: 1. a review of recharge studies in Australia. Aust. J. Soil Res. **40**:397-417.

Pielke, R. A. S., R. Avissar, M. Raupach, A. J. Dolman, X. Zeng, and A. S. Denning. 1998. Interactions between the atmosphere and terrestrial ecosystems: influence on weather and climate. Global Change Biology **4**:461-475.

Prych, E. A. 1998. Using chloride and chlorine-36 as soil-water tracers to estimate deep percolation at selected locations on the U.S. Department of Energy Hanford Site, Washington. U.S. Geol. Surv., Water Supply Pap. 2481:67.

Reed, S. M., D. R. Maidment, and J. Patoux. 1997. Spatial water balance of Texas. Center Res. Water Resour., Tech. Rept. 97-1.

Richardson, C. W. 2000. Data requirements for estimation of weather generation parameters. Trans. Am. Soc. Agric. Engin. **43**:877-882.

Ritchie, J. T., and E. Burnett. 1971. Dryland evaporative flux in a subhumid climate 2. Plant influences. Agron. J. **63**:56-62.

Robins, N. S. 1998. Groundwater Pollution, Aquifer Recharge and Vulnerability. Geol. Soc. Lond. Spec. Pub. No. 130.

Rockhold, M. L., M. J. Fayer, C. T. Kincaid, and G. W. Gee. 1995. Estimation of natural ground water recharge for the performance assessment of a low-level waste disposal facility at the Hanford site. Battelle Pacific Northwest National Laboratory PNL-10508:variably paginated.

Romano, N., and M. Palladino. 2002. Prediction of soil water retention using soil physical data and terrain attributes. J. Hydrol. **265**:56-75.

Sanford, W. 2002. Recharge and groundwater models: an overview. Hydrogeol. J. **10**:110-120.

Scanlon, B. R., and P. C. D. Milly. 1994. Water and heat fluxes in desert soils 2. Numerical simulations. Water Resour. Res. **30**:721-733.

Scanlon, B. R., and R. S. Goldsmith. 1997. Field study of spatial variability in unsaturated flow beneath and adjacent to playas. Water Resour. Res. **33**:2239-2252.

Scanlon, B. R., R. P. Langford, and R. S. Goldsmith. 1999. Relationship between geomorphic settings and unsaturated flow in an arid setting. Water Resour. Res. **35**:983-999.

Scanlon, B. R., R. W. Healy, and P. G. Cook. 2002a. Choosing appropriate techniques for quantifying groundwater recharge. Hydrogeol. J. **10**:18-39.

Scanlon, B. R., M. Christman, R. C. Reedy, I. Porro, J. Simunek, and G. Flerchinger. 2002b. Intercode comparisons for simulating water balance of surficial sediments in semiarid regions. Water Resour. Res. **38**:1323-1339.

Scanlon, B. R., K. Keese, R. C. Reedy, J. Simunek, and B. J. Andraski. 2003a. Variations in flow and transport in thick desert vadose zones in response to paleoclimatic forcing (0-90 kyr): field measurements, modeling, and uncertainties. Water Resour. Res. **39**:1179; doi:1110.1029/2002WR001604.

Scanlon, B. R., Reedy, R. C., and Keese, K. E., 2003b, Estimation of groundwater recharge in Texas related to aquifer vulnerability to contamination: Univ. Texas at Austin, Bur. Econ. Geol. Rept. prepared for the Texas Commission on Env. Qual..

Scanlon, B. R., R. C. Reedy, K. E. Keese, and S. F. Dwyer. In press. Evaluation of evapotranspirative covers for waste containment in arid/semiarid regions. Vadose Zone J.

Schaap, M. G., F. J. Leij, and M. T. van Genuchten. 2001. ROSETTA: a computer program for estimating soil hydraulic parameters with hierarchical pedotransfer functions. J. Hydrol. **251**:163-176.

Scott, R. L., W. J. Shuttleworth, T. O. Keefer, and A. W. Warrick. 2000. Modeling multiyear observations of soil moisture recharge in the semiarid American Southwest. Water Resour. Res. **36**:2233-2247.

Simunek, J., N. J. Jarvis, M. T. van Genuchten, and A. Gardenas. 2003. Review and comparison of models for describing non-equilibrium and preferential flow and transport in the vadose zone. J. Hydrol. **272**:14-35.

Small, E., in press, Climatic controls on diffuse groundwater recharge in semiarid environments, Water Resour. Res.

Sophocleous, M. 1992. Groundwater recharge estimation and regionalization: the Great Bend Prairie of central Kansas and its recharge statistics. J. Hydrol. **137**:113-140.

USDA. 1994. State soil geographic (STATSGO) Data Base. National Resour. Cons. Svc., Misc. Pub. No. 1492, variably paginated.

USDA. 1995. Soil Survey Geographic Data Base, SSURGO. Natural Resour. Cons. Svc., USDA, Misc. Pub. 1527, variably paginated.

Vogelmann, J. E., S. M. Howard, L. Yang, C. R. Larson, B. K. Wylie, and N. van Driel. 2001. Completion of the 1990s National Land Cover Data set for the conterminous

United States from Landsat Thematic Mapper data and ancillary data sources. Photogrammetric Engin. and Remote Sensing **67**:650-662.

Weeks, E. P. 1987. Water use by saltcedar and by replacement vegetation in the Pecos River floodplain between Acme and Artesia, New Mexico. U.S. Geol. Surv. Prof. Pap. 491-G, 33 p.

Welder, G. E. 1987. Hydrologic effects of phreatophyte control, Acme-Artesia reach of the Pecos River, New Mexico. U.S. Geol. Surv. Water Resour. Inv. Rept. 87-4148, 46 p.

Wood, W. W., and W. E. Sanford. 1995. Chemical and isotopic methods for quantifying ground-water recharge in a regional, semiarid environment. Ground Water **33**:458-468.

Wosten, J. H. M., Y. A. Pachepsky, and W. J. Rawls. 2001. Pedotransfer functions: bridging the gap between available basic soil data and missing soil hydraulic characteristics. J. Hydrol. **251**:123-150.

Zhang, L., W. R. Dawes, and T. J. Hatton. 1996. Modeling hydrologic processes using a biophysically based model - Application of WAVES to FIFE and HAPEX-MOBILHY. J. Hydrol. **185**:147-169.

Zhang, L., W. R. Dawes, T. J. Hatton, P. H. Reece, G. T. H. Beale, and I. Packer. 1999. Estimation of soil moisture and groundwater recharge using the TOPOG_IRM model. Water Resour. Res. **35**:149-161.

TABLES

Table 1. General characteristics of modeled sites: site number and county, CPA, Cenozoic Pecos Alluvium aquifer; P, precipitation; PET, potential evapotranspiration; HZ, Humidity Zone (Arnold, 1992): A, arid; SA, semiarid; SH, subhumid; H, humid; site area; topographic slope mean and standard deviation; and mean sand, silt, and clay content.

	Site	*P (mm/yr)*	*PET (mm/yr)*	*P/PET*	*HZ*	*Area (km^2)*	*Slope (%)*	*Slope SD (%)*	*Sand %*	*Silt %*	*Clay %*
1	El Paso	224	2087	0.11	A	2079	0.73	1.36	69	20	11
2	CPA	380	2169	0.18	A	14980	0.38	0.42	60	21	19
3	Midland	380	2169	0.18	A	1388	0.25	0.27	56	20	24
4	Lubbock	474	2034	0.23	SA	2313	0.46	0.72	43	26	31
5	Carson	497	2096	0.24	SA	2363	0.54	0.88	29	35	35
6	Fisher/Jones	620	2132	0.29	SA	1577	0.45	0.42	52	21	26
7	Starr	671	1788	0.38	SA	2474	0.55	0.61	64	13	24
8	Bastrop	810	1732	0.47	SA	1197	1.01	1.04	49	21	30
9	Parker	855	1819	0.47	SA	1464	1.31	1.17	48	23	28
10	Hopkins/Rains	855	1819	0.47	SA	1152	0.52	0.49	41	28	31
11	Upshur/Gregg	855	1819	0.47	SA	1972	1.05	1.20	51	23	26
12	Victoria	933	1651	0.57	SH	2303	0.22	0.31	41	23	36
13	Liberty	1184	1362	0.87	H	3042	0.17	0.31	27	33	40

Table 2: Simulation results for the 4 basic scenarios: measured 30 yr mean annual precipitation (MAP); coefficient of variation (CV); simulated 30 yr mean annual recharge (R); recharge to precipitation ratio (R/P); actual evaporation (AE), actual evapotranspiration (AET), change in water storage (ΔS), and runoff (RO) for monolithic sand, nonvegetated, texturally-variable soils, vegetated monolithic sand, and vegetated texturally-variable soils. Runoff and change in storage is 0 for nonvegetated and vegetated monolithic sand profiles. All ratios are expressed as percent. Units are mm/yr.

Units: mm/yr	MAP		Nonvegetated Sand					Nonvegetated texturally-variable soils					Vegetated sand			Vegetated texturally-variable soils				
			Recharge			AE	PET/AE	Recharge		AE	R_O	ΔS	Recharge		AET	Recharge		AET	R_O	ΔS
Site	Total	CV	Total	CV	R/P			Total	R/P				Total	R/P		Total	R/P			
1	224	0.35	51	0.22	23	173	12.1	19	9	205	0	0.0	2	1	222	0.2	0.1	224	0	-0.7
2	380	0.35	137	0.20	36	243	8.9	80	21	286	14	0.0	34	9	346	11.1	2.9	356	14	-0.7
3	380	0.35	137	0.20	36	243	8.9	56	15	316	7	-0.1	11	3	369	1.5	0.4	375	4	-0.6
4	474	0.23	180	0.24	38	294	6.9	19	4	366	90	-0.4	33	7	441	0.9	0.2	390	85	-1.2
5	497	0.21	174	0.16	35	323	6.5	16	3	286	195	-1.0	29	6	468	0.4	0.1	312	186	-1.4
6	620	0.23	269	0.19	43	351	6.1	88	14	364	168	-0.4	80	13	540	5.6	0.9	435	180	-0.8
7	671	0.24	338	0.19	50	334	5.4	191	29	454	25	0.0	115	17	556	33.8	5.0	610	27	-0.1
8	810	0.21	406	0.20	50	403	4.3	98	12	586	125	0.0	95	12	715	10.1	1.3	619	181	-0.8
9	855	0.22	432	0.18	51	423	4.3	193	23	587	74	0.0	106	12	749	29.0	3.4	727	99	-0.4
10	855	0.22	432	0.18	51	423	4.3	146	17	663	46	0.0	83	10	772	4.7	0.6	792	59	-0.4
11	855	0.22	432	0.18	51	423	4.3	193	23	639	24	0.0	111	13	744	35.1	4.1	795	25	-0.2
12	933	0.23	507	0.22	54	427	3.9	91	10	423	419	-0.2	285	31	648	26.3	2.8	520	388	-0.6
13	1184	0.22	709	0.18	60	475	2.9	230	19	619	335	-0.2	369	31	815	117.7	9.9	748	319	-0.2

Table 3: Power law equation coefficients and residual statistics for estimating long-term (30 yr) mean annual recharge (*y, mm/yr*) from precipitation (*x, mm/yr*). Recharge rates estimated from the power law equation for vegetated, texturally variable soils are shown in Fig. 10.

Model	***Modeling Scenario***	***Coefficients***		r^2	***Residual***	
		a	***b***		σ	$\lvert y_r \rvert$
Power Law ($y = ax^b$)	Nonvegetated, monolithic sand	1.956×10^{-02}	1.484	0.996	8.5	8.5
	Vegetated, monolithic sand	6.131×10^{-07}	2.855	0.854	28.6	28.4
	Nonvegetated, layered soil profiles	1.661×10^{-02}	1.345	0.624	28.2	34.3
	Vegetated, layered soil profiles	3.242×10^{-09}	3.407	0.805	9.2	10.2

r^2: coefficient of determination, σ: standard deviation, $\lvert y_r \rvert$: average absolute deviation

Table 4: Comparison of simulated runoff (RO_{sim}) with spatially averaged runoff estimates (RO_{est}) determined from Reed et al., 1997 for each site. stdev: standard deviation. Units: mm/yr

Site	RO_{sim}	RO_{est}	RO_{est} ***stdev***
1	0	4	5
2	14	0	4
3	4	0	1
4	85	6	1
5	186	3	8
6	179	15	4
7	27	3	7
8	180	118	37
9	99	55	41
10	59	268	53
11	25	232	22
12	387	148	26
13	314	328	22

Table 6. Comparison of simulated recharge estimates (R_{sim}) with recharge estimated using other techniques (R_{est}). Estimation methods include: WP: water potential; UZ CMB: unsaturated zone chloride mass balance approach; GW CMB: groundwater chloride mass balance approach.

Site	R_{sim} *(mm/yr)*	R_{meas} *(mm/yr)*	*Method*	*Ref*
1	0.2	0	WP; UZ CMB	1
4, 5	0.4-0.9	11	GW CMB	2
4	0.9	4-28	UZ CMB	3
6	6	5-30	UZ CMB	3
8	10	5-20	UZ/GW CMB	4
11	35	43-71	GW CMB	5

References: 1: Scanlon et al., 1999; 2: Wood & Sanford, 1995; 3: Scanlon et al., 2003b; 4: Dutton et al., 2003; 5: unpublished data.

FIGURES

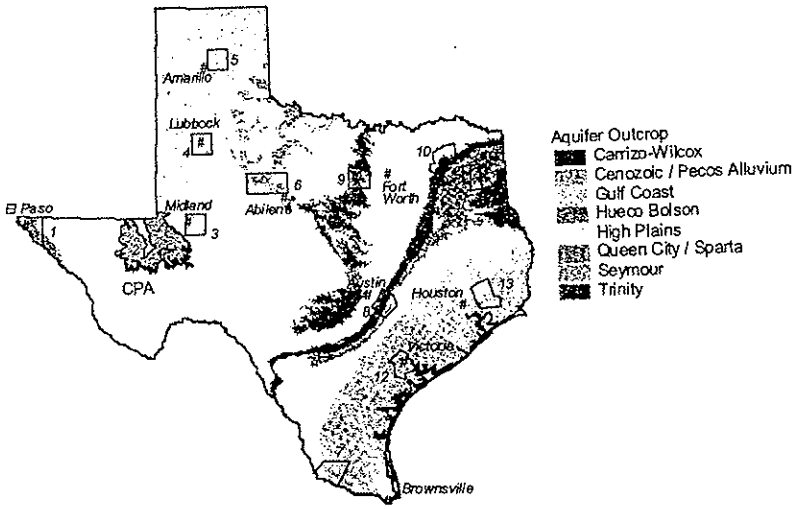

Figure 1: Modeled study sites (1-13), meteorological station locations (italic font), and major porous media aquifer outcrop areas. Sites numbered in order of increasing precipitation; Site 1: El Paso county, 2: Cenozoic Pecos Alluvium aquifer outcrop, 3: Midland county, 4: Lubbock county, 5: Carson county, 6: Fisher and Jones counties, 7: Starr county, 8: Bastrop county, 9: Parker county, 10: Hopkins and Rains counties, 11: Upshur and Gregg counties, 12: Victoria county; and 13: Liberty county.

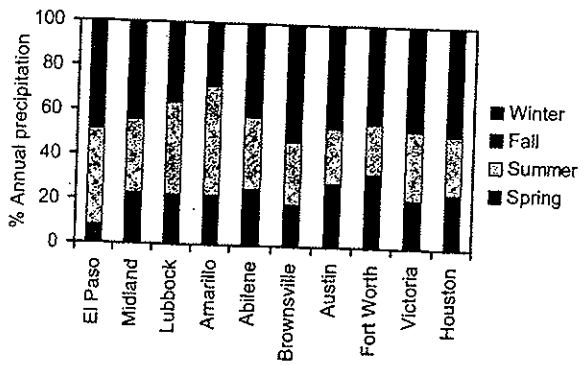

Figure 2. Seasonal distribution of 30 yr average annual precipitation for the 10 meteorological stations used in the simulations in order of increasing precipitation.

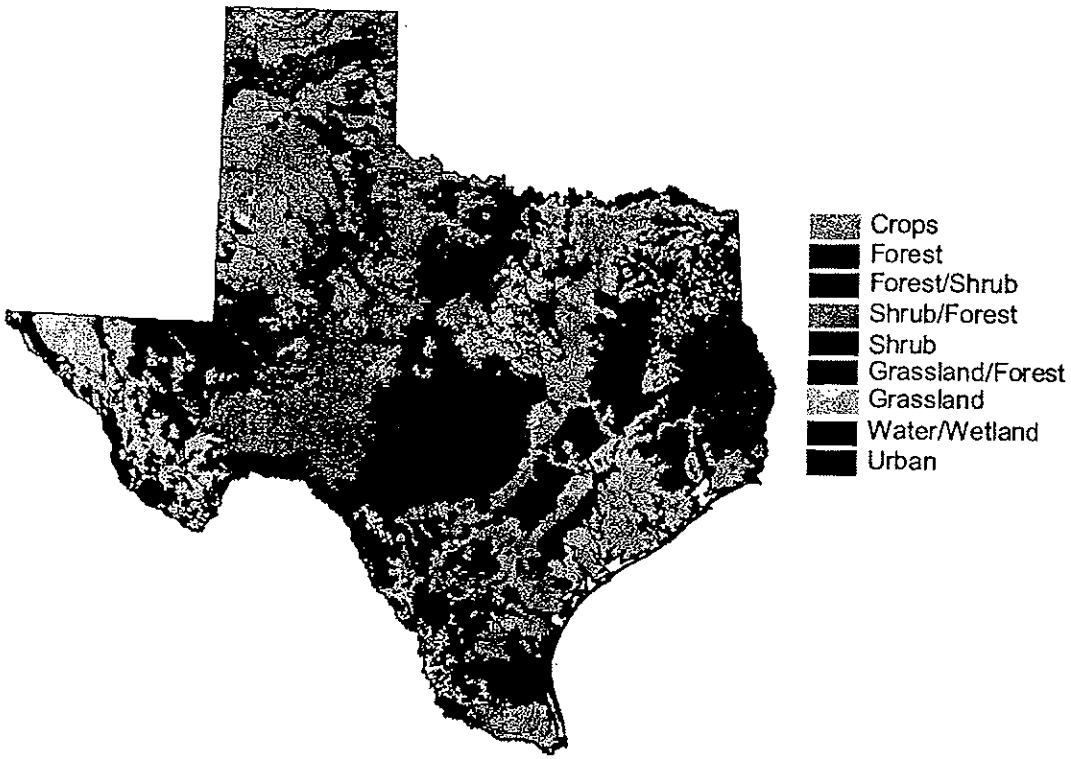

Figure 4: Dominant vegetation associations in Texas (McMahan et al., 1984).

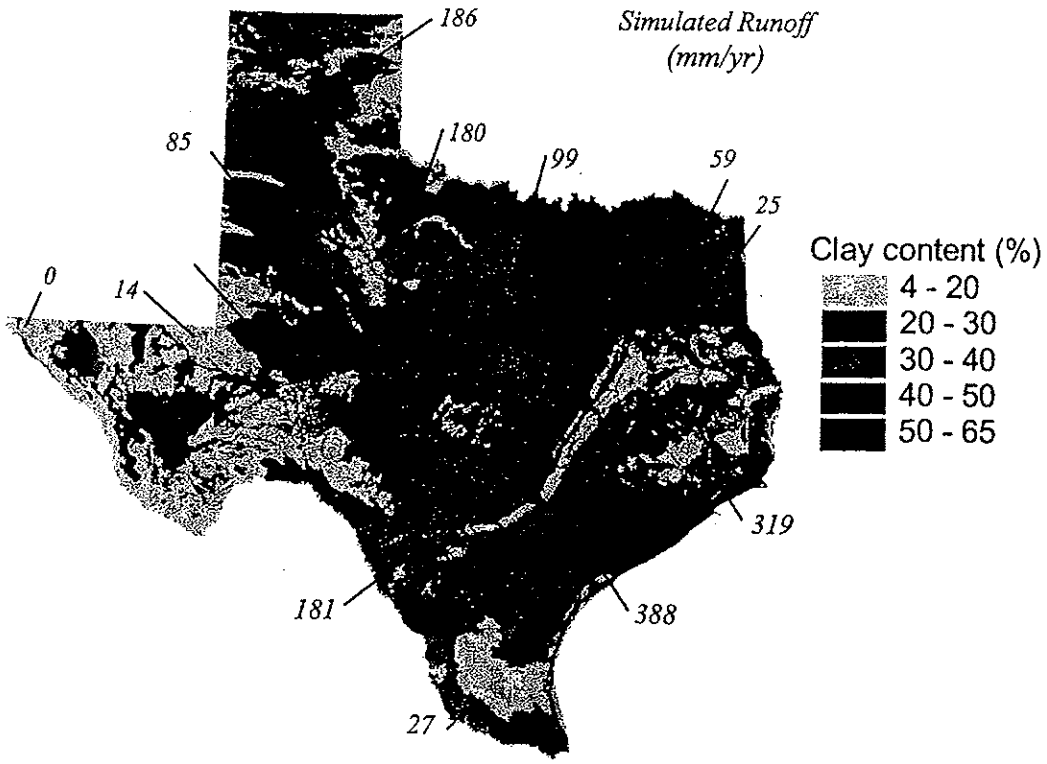

Figure 5: Average soil profile clay content derived from STATSGO database. Water covered areas shown in blue. Simulated runoff using texturally variable soils with vegetation shown in italics.

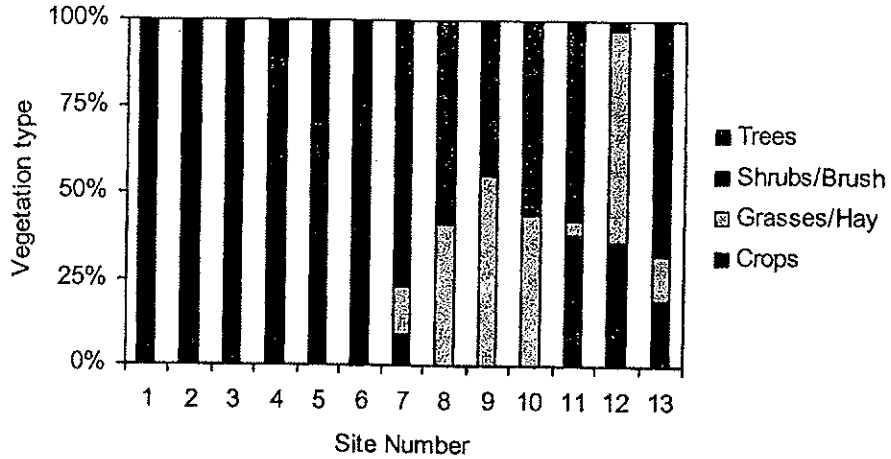

Figure 6: Percentages of vegetation types for each site used in the recharge simulations.

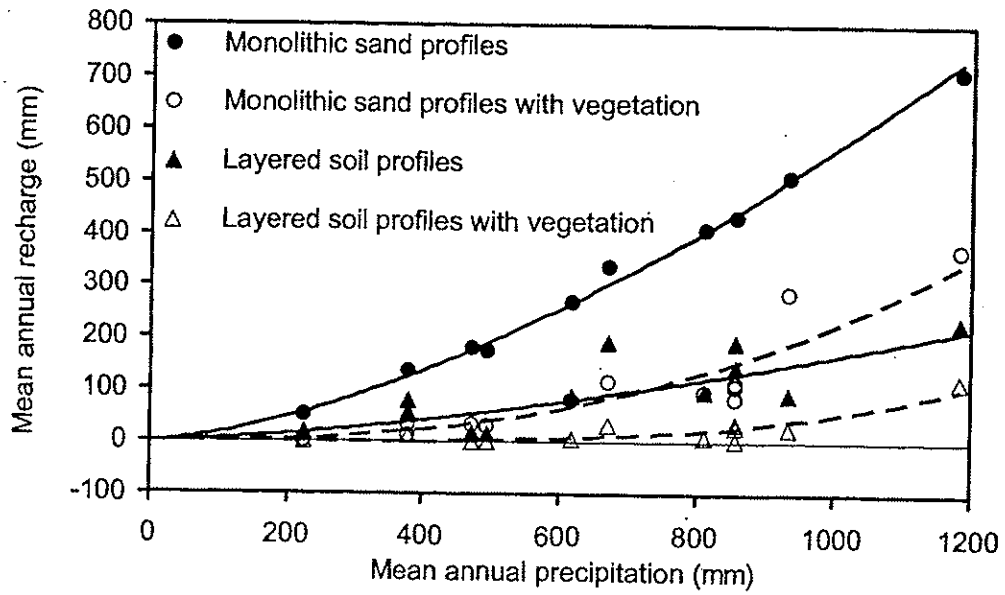

Figure 7: Relationships between long-term (30 yr) mean annual precipitation and simulated mean annual area-weighted recharge. Power law equations were fit to the results for nonvegetated (solid lines) and vegetated (dashed lines) scenarios.

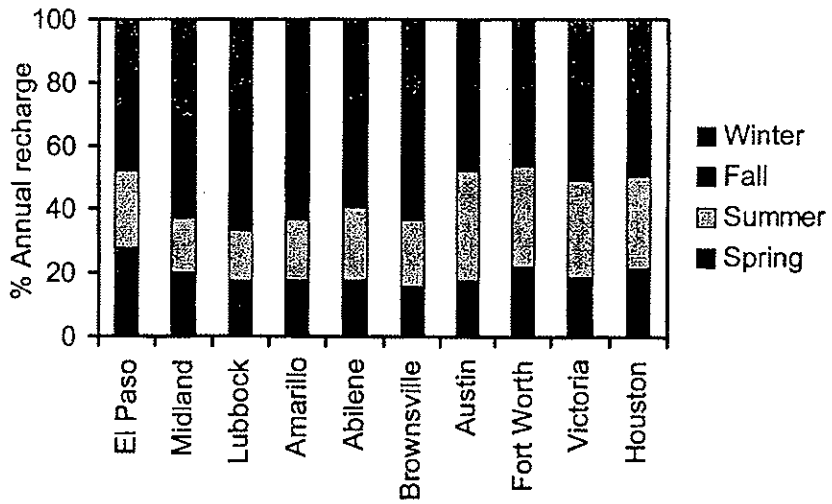

Figure 8: Seasonal distribution of simulated recharge for monolithic sand at each of the meteorological station locations.

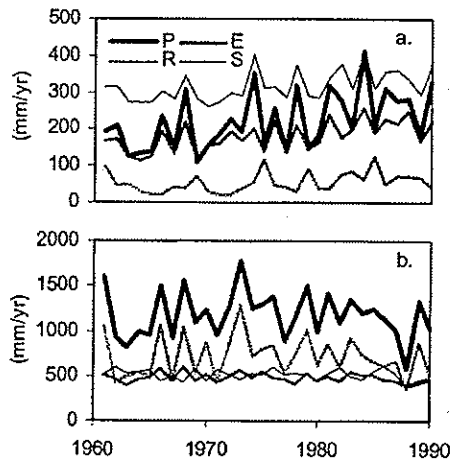

Figure 9. Mean annual water budget parameters for nonvegetated, monolithic sand simulations at site 1 (a) and site 13 (b). P: precipitation, E: evaporation, R: recharge, and S: storage.

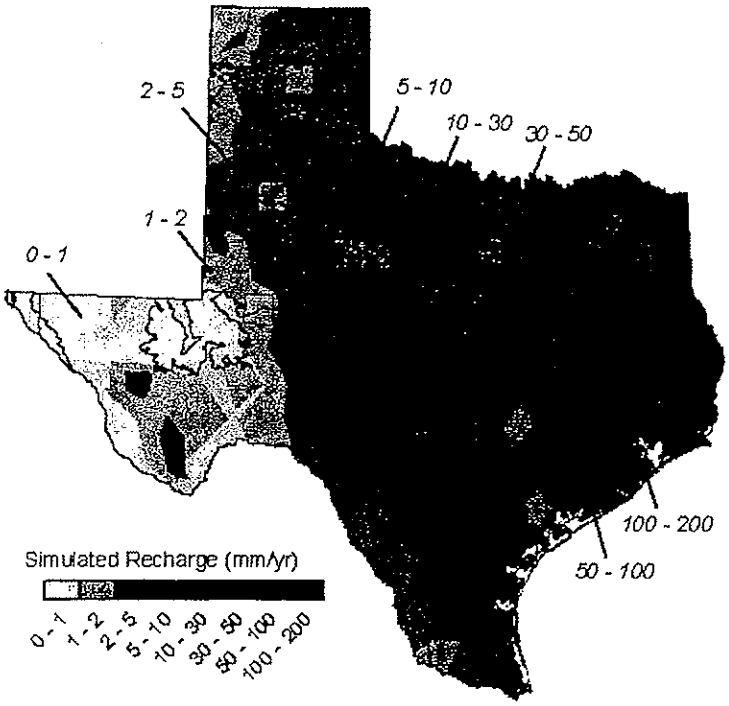

Figure 10: Predicted recharge using the relationship between precipitation and simulated recharge for vegetated, texturally variable soils.

SUPPORTING NONPRINT MATERIAL

Appendix A. Vegetation Parameters

Crop	Max LAI[1]	Max RD[2]	RLD[3] Parameters a	b	c	Crop Growing Season[4]	References
Corn	5.7	2	0.85	0.40	0.02	12: 80-210	1, 2, 3
Cotton	5.75	2.1	0.50	0.01	0.00	1: 121-248; 2: 140-305; 3&4: 135-292; 6: 140-260	1, 4,
Sorghum	3.31	1.5	0.85	0.40	0.01	4: 135-274; 5: 135-288; 7: 61-191; 8: 136-267; 12: 75-205	1, 5, 6,
Hay	2.75	1.35	0.80	0.04	0.01	8&9: 100-315	1, 6, 7,
Soybeans	5	2	0.85	0.05	0.01	13: 121-233	1, 3, 8, 9,

Vegetation Type	Max LAI[1]	RD[2]	RLD[3] Parameters a	b	c	% BA[5]	% Gr[6]	References
Grass	1.2	1	0.50	0.030	0.04			6, 10, 11, 12, 24
Creosotebush	0.4	1	0.40	0.030	0.05	50		10, 11, 13, 14, 15, 24
Shrub	0.5	1.8	0.60	0.045	0.01	1: 60, 20		10, 11, 12, 16, 17, 24, 26
Brush/Shrub	1	1.8	0.64	0.014	0.01	20		10, 11, 12, 16, 17, 24, 26
HS O-Mes Br[7]	1.65	1.8	0.64	0.014	0.01	20		10, 11, 12, 16, 17, 24, 25, 26
P O wo/fo/gr[8]	6	4.3	0.40	0.014	0.02		60	10, 11, 12, 19, 20, 24, 25
Mes Gran pa[9]	2	3.5	0.64	0.014	0.00		60	10, 11, 12, 16, 17, 24
O Mes Jun pa/wo[10]	7	3.5	0.40	0.012	0.02		50	10, 11, 12, 16, 17, 18, 19, 20, 24, 25, 26
P O wo/fo; Wil O-Wat O-BG fo[11]	6	4.3	0.40	0.014	0.02		25	10, 11, 12, 19, 20, 24, 25
P-H fo[12]	3.5	4	1.00	0.012	0.01		25	10, 11, 21, 22, 23, 24

1. LAI: Leaf Area Index; 2. RD: Root Depth (m); 3. RLD: Root Length Density (ρ_{rL} = aexp(-bz) + c (cm roots/ cm soil)); 4. Crop Growing Season: Site Number: day of sowing - day of harvest; 5. % Bare Area: Percentage of area assumed to have no vegetation; 6. % Grass: Percentage of grass assumed to be included in the vegetation type. 7. Havard Shin Oak-Mesquite brush; 8. Post Oak woods/forest/grassland; 9. Mesquite Granjeno parks; 10. Oak Mesquite Juniper parks/woods; 11. Post Oak woods/forest; Willow Oak-Water Oak-Blackgum forest; 12. Pine-Hardwood forest

References: 1. USDA, 1968-1990 2. Howell et al., 1996; 3. Robertson et al., 1980; 4. Bland and Dugas, 1989; 5. Weaver, 1926; 6. Dugas et al., 1999; 7. Dudeck et al., 2003; 8. Holshouser and Jones, 2001; 9. McWilliams et al., 1999; 10 McMahon et al., 1984; 11. Jackson et al., 1996; 12. Ansley et al., 2002; 13. Wallace, 1980; 14. Ackerman et al., 1980; 15. Gibbens, Hicks, and Dugas, 1996; 16. Heitschmidt et al., 1998; 17. James Ansley, pers com; 18. Owens, 1996; 19. Karlik and McKay, 2002; 20. U.S. Army Engineer Research and Development Center; 21. Law et al., 2001; 22. Smialkowski, 1996; 23. Beymer, 2001; 24. Canadell et al., 1996; 25. Jackson et al., 1999; 26. Tierny and Fox, 1987

SUPPORTING NONPRINT MATERIAL REFERENCES

Ackerman, T. L., E. M. Romney, A. Wallace, and J. E. Kinnear. 1980. Phenology of desert Shrubs in southern Nye County, Nevada. Pages 1-4 in Soil-Plant-Animal Relationsips Bearing on Revegetation and Land Reclamation in Nevada Deserts. Brigham Young Univ., Provo, UT.

Ansley, R. J., W. A. Dugas, M. L. Heuer, and B. A. Kramp. 2002. Bowen ratio/energy balance and scaled leaf measurements of CO2 flux over burned Prosopis savanna. Ecological Applications 12:948-961.

Beymer, B. A. 2001. Rainfall Interception Analysis of a Hardwood and Pine Forest. Journal of Undergraduate Study and Independent Research:33-36.

Bland, W. L., and W. A. Dugas. 1989. Cotton root growth and soil water extraction. Soil Sci. Soc. AM. J. 53:1850-1855.

Canadell, J., R. B. Jackson, J. R. Ehleringer, H. A. Mooney, O. E. Sala, and E.-D. Schulze. 1996. Maximum rooting depth of vegetation types at the global scale. Oecologia 108:583-595.

Dudeck, A. E., J. B. Beard, S. I. a. Sifers, and J. A. Reinert. 2003. FloraTeX ® Bermudagrass. University of Florida, Institute of Food and Agricultural Sciences, Bulletin 891. pg 1-14.

Dugas, W. A., R. A. Hicks, and P. Wright. 1998. Effect of removal of Juniperus ashei on evapotranspiration and runoff in the Seco Creek watershed. Water Resour. Res. 34:1499-1506.

Dugas, W. A., M. L. Heuer, and H. S. Mayeux. 1999. Carbon dioxide fluxes over bermudagrass, native prairie, and sorghum. Agric. For. Meteorol. 93:121-139.

Gibbens, R. P., R. A. Hicks, and W. A. Dugas. 1996. Structure and function of C3 and C4 Chihuahuan Desert plant communities. Standing crop and leaf area index. J. Arid. Env. 34:47-62.

Heitschmidt, R. K., R. J. Ansley, S. L. Dowhower, P. W. Jacoby, and D. L. Price. 1998. Some observations from the excavation of honey mesquite root systems. J. Range Management 41:227-230.

Holshouser, D. L., and B. P. Jones. 2001. Site-Specific Management Strategies to Attain and Maintain Adequate Soybean Leaf Area. Annual Report 2001- Virginia Tech - Tidewater Agricultural Research & Extension Center.

Howell, T. A., S. R. Evett, J. A. Tolk, A. D. Schneider, and J. L. Steiner. 1996. Evapotranspiration of corn -- Southern High Plains. Pages 158-166 in C. R. Camp, E. J. Sadler, and R. E. Yoder, editors. Evapotranspiration and Irrigation Scheduling. Am. Soc. Agric. Engin., San Antonio, TX.

Jackson, R. B., J. Canadell, J. R. Ehleringer, H. A. Mooney, O. E. Sala, and E. D. Schulze. 1996. A global analysis of root distributions for terrestrial biomes. Oecologia 108:389-411.

Jackson, R. B., L. A. Moore, W. A. Hoffmann, W. T. Pockman, and C. R. Linder. 1999. Ecosystem Rooting Depth determined with caves and DNA. Proc. Natl. Acad. Sci. USA. Ecology 96:11387-11392.

Karlik, J. F., and A. H. McKay. 2002. Leaf area index, leaf mass density, and allometric relationships derived from harvest of Blue Oaks in a California oak savanna. USDA Forest Service Gen. Tech. Rept. PSW-GTR-184.

Law, B. E., S. van Tuyl, A. Cescatti, and D. D. Baldocchi. 2001. Estimation of leaf area index in open-canopy ponderosa pine forests at different successional stages and management regimes in Oregon. Agric. Forest Meteorol. 108:1-14.

McMahon, C. A., R. G. Frye, and K. L. Brown. 1984. The vegetation types of Texas including cropland. Texas Parks and Wildlife Department, 40p.

McWilliams, D. A., D. R. Berglund, and G. J. Endres. 1999. Soybean Growth and Management Quick Guide. A-1174, June 1999. North Dakota State University and University of Minnesota.

Owens, M. K. 1996. The role of leaf and canopy level gas exchange in the replacement of Quercus Virginiana (Fagaceae) by Juniperus Ashei (Cupressaceae) in semiarid savannas. Am. J. Botany 83:617-623.

Robertson, W. K., L. C. Hammond, P. A. Forsyth, J. T. Johnson, and K. J. Boote. 1980. Effects of plant-water stress on root distribution of corn, soybeans, and peanuts in sandy soil. Agron. 72:548-555.

Smialkowski, J. 1996. Photosynthetically Active Radiation Measurements in Pure Pine and Mixed Pine Forests in Poland. *in* International Symposium on Air Pollution and Climate Change Effects on Forest Ecosystems, Riverside, CA.

Tierney, G. D., and T. S. Foxx. 1987. Root Lengths of Plants on Los Alamos National Laboratory Lands. LA-10865-MS, Los Alamos National Laboratory.

U.S. Army Engineer Research and Development Center. Undated. Vegetation and the structural integrity of levees: Results of field investigations, REMR Technical Note EI-M-1.3, Geotechnical and Structures Laboratory, Vicksburg, MS,

U.S. Department of Agriculture, 1968-1990, National agricultural statistics service data base – County Level Data for: Texas crops: Accessed July 17, 2003, at URL http://www.nass.usda.gov:81/ipedbcnty/c_TXcrops.htm

Wallace, A. 1980. Depth distribution of roots of some perennial plants in the Nevada Test Site Area of the Northern Mojave Desert. Pages 199-205 in Soil-Plant-Animal Relationships Bearing on Revegetation and Land Reclamation in Nevada Deserts. Brigham Young Univ., Provo, Utah.

Weaver, J. E. 1926. Root Development of Field Crops. McGraw-Hill Book Company, INC.

ENCLOSURE

#6

SECTION 10

Türkiye Toprak İlmi Derneği
Bildiri Özetleri

Ana Sayfaya Dönüş

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Sustainability of Groundwater in Salalah Catchment Area, Sultanate of Oman

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Abstract

This study is an introductory stage for a current research project on the sustainability of groundwater in Salalah A of Oman. The Salalah plain extends over a 253 km2 area to the north of the Omani coastline of the Arabian Sea t Mountains of Dhofar. The area is recharged by rainfall on the mountains and on the plain. The annual recharge is 40 Mm3yr-1. About 94% of this amount comes from the mountains. Water is being abstracted from the Salalah a meet the increasing domestic and agricultural demands of the city. Average annual discharge is estimated at 44 M Agriculture consumes about 87% of this amount. From these estimates, it is obvious that the area will face a maj these rates are maintained or increased and no management plans are implemented. Over abstraction from the a saline water intrusion in addition to the decline of groundwater storage. Present studies showed that the salinity o increasing but not to the extent to prevent its use for agriculture. However, this rate of increase is alarming of a s problem the area might face in few years from now. Policies have to be implemented to protect the Salalah area g and the supplying aquifers, i.e. the Jebel. Other solutions to enhance the infiltration rates and resist the saline wa such as constructing dams and the use of treated wastewater, are required.

Introduction

Salalah, the southern capital of Oman, is on the southern coast of Sultanate of Oman. It lies on a flat coastal plain of which rise the Jebel or mountains. Water is supplied to this town through two well fields situated to the north o plain. The main Salalah well field was drilled in 1970's. Due to the increase in water demand, the Sa'ada well field 1986 with 3 wells to the north of the Salalah well field. The region can be divided into three main areas: the Salal plain, the Jebel and the Nejd. The plain extends to about 10 km from the coast with an elevation rising to 100 m. mountain rising to 1000 m above sea level, borders the plain and extends along the southern coast of Oman. The about 20 km wide north of Salalah. The Nejd, a flat arid area, lies inland of the Jebel at an elevation of about 650 level and slopes gently to the north. There is extensive agriculture on the coastal plain and there are a large num groundwater abstractors in the area to provide water for irrigation. Other water supply for this area comes from p sprigs that issue from the edge of the Jebel. These are tapped off near the source and channelled to several large

Salalah area has a very different climate from the rest of the country. It has a hot and arid climate during the win cooler summer monsoon period (Kharif) between June and September. The monsoon winds come from the south persistent fog and light rain, much of the rain falling on the southern slopes of the Jebel. These winds are largely the extreme summer heating that occurs in the vast inland desert of the Rub Al Khali or Empty Quarter (Schemen The monsoon clouds are prevented from moving inland by mountains and are pushed against the Jebel forming e of high elevation fog. The cloud bank associated with the monsoon is about 140 km long and less than 80 km wid 1988). However, heavy rains may occur at any season during rare cyclonic storms. The regional geology of Salala characterized by two distinct regions separated by a major fault, which divides the Salalah Plain from the Jebel. T consists of a thick sequence of limestone with some shales and rises to 1000 m above sea level. There are four m units: the Tertiary Dammam, Ru and Umm Er Rahhuma, which form Hadramaut Group, and the Cretaceous limest plain has a uniform slope of approximately 0.01 and is crossed by a number of shallow wadi systems (Flint and Ri

Methodology

The available data from the Jebel and the plain were collected from different locations as shown in Table 1. Sever have been made to estimate the recharge and discharge rates on this area along different periods since 1976. The the fresh groundwater of the Salalah plain can be derived from four alternative mechanisms. Subsurface flow from the infiltration of springs at the foot of the Jebel and the infiltration of rain falling on the plain directly are the mai mechanisms. Infiltration due to wadi flood flow is the fourth mechanisms, though it is of much less importance du This study compares some of these previous results of estimating the recharge and the abstraction rates in the Sa These studies cover the Salalah plain and the Jebel. Salalah plain area is 253 km2 and the Jebel area is 536 km2. results will be determined for final comparison in order to determine an average rate for the difference between t outflows of the groundwater. Groundwater quality will be checked to identify its possible uses. The main issue of be the salinity of the groundwater since the area is near the southern coast of Oman. The amount of inflow and o sea will be determined in order to estimate the saline water intrusion. In addition, electrical conductivity for severa taken from Dames and Moore study collected in 1991 will be compared with samples taken from similar locations i the quality of groundwater can be determined and thus the use of this water.

Results

Studies about the groundwater in Salalah were done by several consultant companies along the past 30 years for of Water Resources. Some of these companies are: Sir William Halcrow & Partners (1977), in Tetratech (1978), Jo Sons (1976), in Tetratech (1978), Hydrotechnica (1986), Dames and Moore (1992) and Entec Europe Limited (19 shows estimates of groundwater inflow of the Jebel by the mentioned companies and an average value for all the

Table 1. Salalah data summary

Data Type	Details of Records	
Rainfall	11 stations on plain + 12 stations on the Jebel	Salalah airport record from 1942, most records up to December 31, 1996
Wadi Flows	Wadi Jarziz Wadi Sahalnawt Wadi Rzat Wadi Ain Hamran	1983- 1994 1983-1994 1983-1994 1992-1994
Spring Flows	6 stations on plain (+ 9 on the Jebel)	Monthly data, 4 started in 1977, 2 in 1991, records up to 1995
Abstractions	Monthly data	13 individual Dhofar Municipality wells 1991 to 1996, Salalah well field 1972 to 1987
	Yearly data	Salalah, Sa'ada and military well fields 1972 to 1987
Static Water Levels	21 boreholes on plain	1980's to 1996
	14 boreholes on Jebel front	1980's to 1996
Aquifer Parameters	T and K: 25 locations	Various tests including 4-day tests
	6 storage coefficients	Tests with observation wells
	Calibrated model results	MacDonald (1990)
Well Inventory	44 wells	36 completion logs

If the most recent studies were considered, Dames and Moore (1992) and Entec Europe Limited (1998), a better can be established since they took more considerable factors in their studies. Figure 1 shows this comparison and for their results. The annual average rainfall on the plain is around 110 mm whereas in the Jebel it is about 260 m and Moore, 1992). The annual average rainfall is 84.8 mm on the plain and 275 mm on the Jebel (Entec, 1998). T of recharge due to rainfall are 2.5% from the plain and 25% from the Jebel according to Dames and Moore study, 20% and 35% in the Entec study as shown in Table 3. The saline water intrusion leads to a concern about the wa knowing the high demand needed for irrigation.

Table 2. The Jebel Groundwater inflow estimates.

Source	The Jebel Groundwater inflow estimates, Mm^3/y
Sir William Halcrow & Partners (1977), in Tetratech (1978)	10-141
John Taylor & Sons (1976), in Tetratech (1978)	29-128
Hydrotechnica (1986)	24-31.6
Dames and Moore (1992)	31.8
Entec Europe Limited (1998)	43.2
Average	51.3

Groundwater Quality

The results from Dames and Moore show decline in the storage water of 7.9 Mm3yr-1. This is considered high con Entec estimate of 1.7 Mm3yr-1. However, both studies prove that saline water intrusion exists in the area. Figure : electrical conductivity of pumped groundwater in 1983 and 1991 (Dames and Moore, 1992). The increase in saline intrusion does not appear to have significant affect on the EC profile in the main freshwater zone which has an av about 1000 mScm-1. Sea water intrusion is expected to continue its increasing which will cause serious problems i are implemented.

Conclusions

The study covers a total area of 789 km2, 253 km2 of Salalah Plain and 536 km2 of the Jebel. Studies have evalu situation in the Salalah area since 1970's. Some records are since 1940's such as the one in Salalah airport area. T of the records gauges and monitoring wells are mainly along the well fileds with others from different locations on and the Jebel. Some records of very high value are likely to be biased. However, recent studies are of more reliabi consider several important parameters such as infiltration from different sources, impact of fog in enhancing preci evaporation and evapotranspiration, leakage from water supply network, geology of the area, etc. The average va recharge to the groundwater is 37.5 Mm3yr-1 from Jebel inflow and 2.45 Mm3yr-1 from rainfall. The total discharg Mm3yr-1. Thus, the groundwater in Salalah catchment is extensively declining and a policy will be required to prot the high pumping which makes 87% of the discharge. Another policy is required to protect the groundwater of the makes 93.9% of the recharge. This recharge may reach over along term an average of 45 Mm3yr-1. This groundw support both well fields and the extensive abstraction of irrigation water on the plain.

$\frac{2.45\times10^6\ m^3/yr}{253\ km^2 \cdot (1000m)^2/km} \Rightarrow 9.7\times10^{-3}\ m/yr \Rightarrow 9\ mm/yr$

Table 3. Comparison of Entec and Dames and Moore (1992) water balances for Salalah.

	Component	Entec estimate, Mm^3/yr	Dames & Moore estimate, Mm^3/yr	Average, Mm^3/yr
Inflows	Jebel front GW inflow and springs	43.2	31.8	37.5
	Rainfall on plain	4.3	0.6	2.45
outflows	Agric. consumption	44.9	31.7	38.3
	Potable system losses	4.3	7.1	5.7
	Net outflow to sea	-1.7	1.5	-0.1
Change in storage	(outflow minus inflow)	0	7.9	3.95

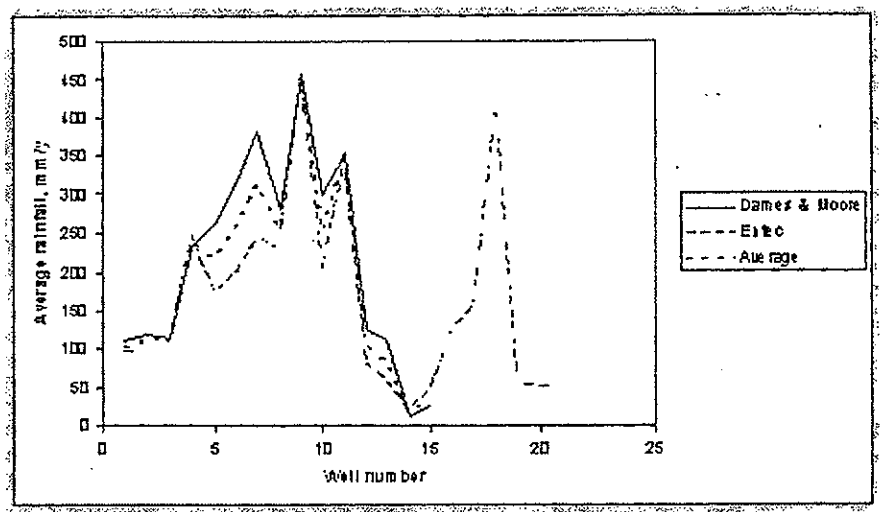

Figure 1. Annual rainfall data from Entec and Dames and Moore studies.

There is some saline water intrusion in addition to the decline of groundwater storage. Sea water intrusion is a prc concern since lots of farms are situated along the coastal line of Salalah area. So, additional solutions should be pı resist this problem. The use of treated wastewater and construction of several dams to enhance the filtration rates rainfall may appear to be valid solutions.

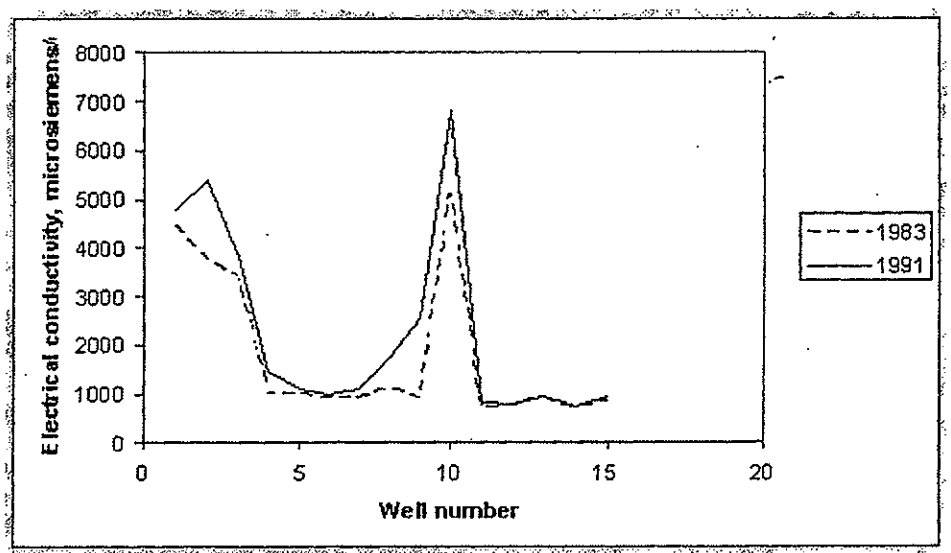

Figure 2. Electrical conductivity of pumped groundwater.

References

. Dames and Moore, 1992. Water and Wastewater Masterplan for Salalah: Dhofar Municipality, Final Report.
. Dames and Moore, 1992. Investigation of The Quality of Groundwater Abstracted from the Salalah Plain: Dhofar Final Report.
. Entec Europe Limited, 1998. Consultancy Services for The Study of Development Activities on Groundwater Quali Adai, Al Khawd and Salalah Well field Protection Zones, Contract No 96-2133, Final Report. Volume 4, Hydrogeolo Modelling, Salalah. Ministry of Water Resources.
. Flint, R. B. and Roppin, P. W., 1986. Geological Reassessment of the Salalah Plain Aquifer. Sultanate of Oman, C Conservation of Environment and Water Resources. Public Authority for Water Resources Report.
. Halcrow, Sir William Halcrow and Partners, 1977. Surveys and Investigations for Land and Water Resources Deve Dhofar, Annex 2- Water Resources and Irrigation. Ministry of Agriculture and Fisheries.
. Hydrotechnica, 1986. Robat-Awqad Supply Scheme, Report of pre-feasibility Study.
. Price, M. R. S., Ahmed Bin Hamoud Al Harthy, Whitcombe, R. P., 1988. Fog Moisture and its Ecological Effects in

Arid Lands Today and Tomorrow Conf., E. E. Whitehead et all (eds.), Westview Press, Boulder, Colo., 69-88. (881)
. Schemenauer, R. S., 1989. Report to the World Meteorological Organization Technical Coordination Division on tl for Fog Water Collection in the Dhofar Region of Southern of Oman. Cloud Physics Research Division, Atmospheric Service, Environment Canada.
. Taylor, J. and Sons, 1978. Well field Completion Report Presenting Information Collected on the Water Resource: Salalah Plain.

Sayfa Başı

ENCLOSURE

#7

THIS PAGE IS TO REMAIN WITH DOE O 442.1A

THIS PAGE TRANSMITS AN ADMINISTRATIVE CHANGE TO DOE O 442.1, DEPARTMENT OF ENERGY EMPLOYEE CONCERNS PROGRAM, DATED 2-1-99. THIS PAGE ALSO CANCELS DOE O 442.1 AND REISSUES IT AS DOE O 442.1A, DEPARTMENT OF ENERGY EMPLOYEE CONCERNS PROGRAM, DATED 6-6-01.

THE ADMINISTRATIVE CHANGE THAT OCCURRED WAS TO BRING THIS DIRECTIVE INTO COMPLIANCE WITH THE NATIONAL NUCLEAR SECURITY ADMINISTRATION.

QA: QA

U.S. Department of Energy
Washington, D.C.

ORDER

DOE O 442.1A

Approved: 6-6-01
Review Date: 2-1-01

SUBJECT: DEPARTMENT OF ENERGY EMPLOYEE CONCERNS PROGRAM

1. OBJECTIVE. As a service to all Departmental Elements, the following will be to establish a Department of Energy (DOE) Employee Concerns Program (ECP) that ensures employee concerns related to such issues as the environment, safety, health, and management of DOE and the National Nuclear Security Administration (NNSA) programs and facilities are addressed through —

   a. prompt identification, reporting, and resolution of employee concerns regarding DOE facilities or operations in a manner that provides the highest degree of safe operations;

   b. free and open expression of employee concerns that results in an independent, objective evaluation; and

   c. supplementation of existing processes with an independent avenue for reporting concerns.

2. CANCELLATIONS. DOE O 442.1, DEPARTMENT OF ENERGY EMPLOYEE CONCERNS PROGRAM, dated 2-1-99. DOE 5480.29, EMPLOYEE CONCERNS MANAGEMENT SYSTEM, dated 1-15-93. Current ECP's, implemented pursuant to DOE 5480.29, will remain in effect until superseded by revised programs implemented under this Order.

3. APPLICABILITY.

   a. DOE Elements, including NNSA. Except for the exclusion in paragraph 3c, this Order applies to all DOE Elements.

   b. Contractors. Except for the exclusions in paragraph 3c, the Contractor Requirements Document (CRD), Attachment 1, sets forth requirements for management and operating and management and integration contractors of DOE-owned or -leased facilities.

   c. Exclusions. Activities of the Naval Reactors Program conducted under Executive Order 12344 are excluded from this Order.

4. REQUIREMENTS.

   a. ECP Criteria. The ECP must meet the following criteria.

      (1) Possess interfaces with the following organizations:

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All Departmental Elements

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Office Economic Impact and Diversity
Office of Employee Concerns

(a) other DOE, including NNSA and DOE contractor ECPs,
(b) external regulatory bodies that require employee concerns programs,
(c) Headquarters Office of Employee Concerns, and
(d) labor organizations, where applicable.

(2) Establish documented program plans describing methods and processes used to implement program requirements.

(3) Require that DOE, including NNSA and DOE contractor employees (i.e., any person working for a DOE contractor or subcontractor on a DOE project) be informed of the following:

(a) ECP process;

(b) employees are encouraged to first seek resolution with first-line supervisors or through existing complaint or dispute resolution systems, but that they have the right to report concerns through the DOE ECP; and

(c) management's intolerance for reprisals against or intimidation of employees who have reported concerns.

(4) Provide and publicize a 24-hour hot-line (e.g., voice mail or e-mail system).

b. Concerns Processing.

(1) Concerns must be processed in one of the following manners:

(a) investigated or otherwise evaluated through the ECP, in coordination with DOE, including NNSA or external offices when required;

(b) referred to other offices or programs and tracked by the ECP until they are resolved (referral of a concern);

(c) transferred to another DOE or contractor organization with jurisdiction over the issues, when those issues are outside the scope of the ECP (transfer of a concern); or
(d) closed as prescribed in paragraph 4c.

(2) ECP personnel must document employee concerns in sufficient detail to permit investigation or other appropriate levels of review.

(3) Concerns must be tracked until closure.

(4) Unless otherwise agreed to by the employee, an organization other than that of the employee's immediate supervisor must conduct the investigation. Similarly, individuals or organizations outside the concerned employee's organization should not be selected to conduct the investigation where their involvement presents a conflict of interest.

(5) If the concerned employee requests confidentiality, his or her identity must not be disclosed during the investigation or other process used to evaluate the concern. However, ECP personnel should advise employees of the limitations of its ability to protect confidentiality under certain circumstances. For example, the concern may involve action taken against the employee for which relief is sought, or the employee may be closely associated with the concerns.

(6) ECP personnel must evaluate and attempt to resolve employee concerns in a manner that protects the health and safety of both employees and the public, ensures effective and efficient operation of programs, and uses alternative dispute resolution techniques whenever appropriate.

(7) ECP personnel must immediately report to an appropriate line manager (i.e., one with program, project, or health and safety responsibility) and/or the Environment, Safety and Health program office those concerns that involve an imminent danger or condition or a serious condition.

(8) Appropriate offices (i.e., those with program, project, or health and safety responsibility) must determine whether DOE, including NNSA or its contractors have taken action to minimize, correct, or prevent recurrence of program, process, or management weaknesses identified and substantiated through the ECP.

(9) Reports of concerns must be reviewed for classified information and, if classified, sanitized by an authorized classifier.

e. Closure.

(1) An employee concern case is designated as closed when one of the following occurs:

(a) the concern has been investigated; necessary corrective actions have been identified (e.g., issuance of a non-conformance report); the office responsible for taking the corrective action has accepted jurisdiction over the matter; and the resolution has been documented in a formal tracking system;

(b) the concern has been investigated and no corrective action is deemed necessary;

(c) the subject matter of the concern is outside the scope of the ECP and the concern has been transferred to another organization with jurisdiction over the subject matter;

(d) ECP personnel have advised an employee raising a concern that is outside the scope of the ECP of available means to have the concern addressed, if direct transfer of the concern to another organization is not appropriate (e.g., allegations subject to the Equal Employment Opportunity complaint process, claims for workplace injuries);

(e) the ECP determines that the issues are frivolous or too general to investigate; and

(f) the concerned employee has been notified that the concern has been closed.

(2) If the ECP does not resolve a concern to the satisfaction of the concerned employee, the concerned employee must be advised if there are any offices with authority or responsibility for addressing the subject matter of the concerns.

d. Documents and Records.

(1) At a minimum, the ECP office must prepare and maintain the following records:

(a) concern log,
(b) concern reports,
(c) concern investigation and resolution summaries, including a description of the basis for closing the concern, consistent with paragraph 4c above;
(d) management assessment results, and
(e) quarterly and annual reports.

(2) ECP personnel must submit quarterly and annual reports to the head of the field element and the Office of Employee Concerns. The reports must address the following:

(a) employee concerns activity levels for the period,
(b) nature of the concerns,
(c) resolution of the concerns, and
(d) other information required under ECP directives for the effective coordination of ECPs.

(3) In maintaining ECP records, steps must be taken to protect the identity of the concerned employee consistent with the employee's request for confidentiality and the provisions of the Privacy Act and the Freedom of Information Act.

(4) Federal records cannot be destroyed unless authorized by the Archivist of the United States, National Archives and Records Administration (NARA). Authorities are found in the General Records Schedule of the Government, as issued by NARA, and in NARA-approved DOE records disposition schedules (Standard Forms 115). Should any or all ECP records not be "covered" by authorized records disposition schedule, the responsible ECP manager must seek NARA authorization (a records disposition schedule) through the cognizant local records officer in liaison with the Departmental Records Officer.

e. Training and Qualification. Personnel responsible for implementing the ECP or investigating concerns must be trained to properly carry out their responsibilities (e.g., training on the identification and classification of health and safety issues, how to investigate workplace, and administrative issues and dispute resolution techniques).

f. Management Assessment. The ECP manager must assess, at least annually, the effectiveness of the ECP and processes used to implement this Order. Problems that hinder the ECP from achieving its objectives must be identified and corrected.

5. RESPONSIBILITIES.

a. Director, Office of Employee Concerns.

(1) Develops, promulgates, and maintains ECP directives.

(2) Assists DOE and contractor organizations in implementing ECP directives.

(3) Analyzes feedback provided by quarterly and annual ECP reports and site visits to DOE and contractor organizations to ensure ECPs are adequately implemented, best practices are shared, and related directives are improved.

(4) Decides which concerns that are brought to the attention of Office of Employee Concerns the office should seek to resolve, which warrant referral or transfer to another office for further review, or which warrant no further action.

b. Secretarial Officers and Field Element Manager/NNSA Deputy Administrators.

(1) Designate the management position or positions responsible for developing and implementing the ECP.

(2) Direct the ECP and provide adequate resources and training for effective implementation.

(3) Ensure implementation of ECPs required by contract for contractors under their jurisdiction.

(4) Use management assessment results to verify the adequacy and implementation of the ECP and improve performance.

c. ECP Managers.

(1) Develop and submit ECP program implementation documentation to the Secretarial Officer or field element manager, as appropriate, for approval.

(2) Implement the approved ECP and ensure concerns are processed as required by this Order.

(3) Publicize ECP processes, employee rights and responsibilities to report concerns through these processes, and management's intolerance for reprisals against employees who have reported concerns.

(4) Maintain an employee concerns tracking system and a secure filing system.

(5) Decide which concerns that are brought to the attention of the ECP the ECP office should seek to resolve, which warrant referral or transfer to another office for further review, or which warrant no further action.

(6) Assist in evaluation and resolution of employee concerns.

(7) Transfer concerns to other programs or processes if the concern is deemed to be outside the scope of the ECP. Review and evaluate responses from other organizations to which concerns were referred, request further action when necessary, and provide feedback to those organizations that have a need to know about the outcome of the ECP process.

(8) Document that an individual, office, or organization has accepted responsibility for minimizing, correcting, and preventing recurrence of concerns that have been substantiated through the ECP process.

(9) Prepare quarterly and annual reports and review them for lessons learned and possible adverse trends.

(10) Use self-assessment or outside review to conduct management assessments of their ECPs. Assess the results with the Headquarters or field element manager, and take any necessary actions to improve program operations.

(11) Coordinate with DOE contracting officers to determine the existence of contract requirements for the establishment of contractor ECPs and the means and criteria by which such contractor ECPs will be evaluated.

(12) Advise appropriate levels of management when actions are either ineffective or not timely in resolving concerns or correcting identified deficiencies.

d. Assistant Secretary for Environment, Safety and Health (EH-1).

(1) Acts as DOE's independent element responsible for safety aspects relative to public and worker health and safety, environmental protection, oversight of these areas and programs designed for the protection of special nuclear materials, classified information, and sensitive unclassified information.

(2) Advises and assists organizations in investigations of environmental, safety, and health concerns.

(3) Assesses and reports to the Secretary of Energy on safety-related activities conducted pursuant to this Order as part of assessments of safety-related performance of the Secretarial Offices, field elements, and contractors.

(4) As necessary, reviews proposed statutes, regulations, standards, and requirements for their application to and potential impact on DOE programs.

e. Director of Human Resources Management.

(1) Processes and resolves employee concerns/complaints filed under administrative and negotiated grievance procedures.

(2) Provides health services for Federal employees.

6. REFERENCES.

a. DOE G 442.1-1, DEPARTMENT OF ENERGY EMPLOYEE CONCERNS PROGRAM GUIDE, which contains guidance on implementation of the ECP.

b. Executive Order 12344, Naval Propulsion Act (44 U.S.C. 7158, note).

c. Privacy Act of 1974, Public Law 93-579, 88 Stat. 1896 (5 U.S.C. 552a), as amended, which establishes laws to implement the Privacy Act.

d. Freedom of Information Act of 1974, Public Law 93-502, 5 U.S.C. 552, as amended, which establishes law to implement the Freedom of Information Act.

e. 10 Code of Federal Regulations, Part 708, DOE Contractor Employee Protection Program.

f. 29 Code of Federal Regulations, Part 1960.28, Employee Reports of Unsafe or Unhealthful Working Conditions.

g. 29 Code of Federal Regulations Part 24, Procedures for Handling Discrimination Complaints Under Federal Protection Statutes, which established the Department of Labor's procedures for investigating and adjudicating allegations of whistleblower reprisal under certain Federal statutes.

h. Price-Anderson Amendments Act of 1988 (Pub. L. 100-49, August 20, 1988), implemented by DOE under 10 CFR Part 820.

i. DOE O 440.1A, WORKER PROTECTION MANAGEMENT FOR DOE FEDERAL AND CONTRACTOR EMPLOYEES, which establishes the framework for an effective worker protection program by providing Federal and contractor workers with a safe and healthful workplace.

j. P.L. 106-65, DoD Authorization Act of 2000, which statutorily establishes NNSA.

7. DEFINITIONS.

a. Alternative Dispute Resolution. Process for resolving disputes through use of a neutral third party in an attempt to avoid judicial or administrative litigation. Forms of alternative dispute resolution include mediation, partnering, ombudsmanship, neutral evaluation, nonbinding arbitration, binding arbitration, and mini-trial.

b. Conflict of Interest. A situation in which the person responsible for investigating an employee concern could be associated either directly or indirectly with that concern or an investigative task is assigned to a person who might have submitted the concern.

c. Employee. Any person working for DOE, including NNSA or a DOE contractor or subcontractor on a DOE project.

d. Employee Concern. A good faith expression by an employee that a policy or practice of DOE or one of its contractors or subcontractors should be improved, modified, or terminated. Concerns can address issues such as health, safety, the environment, management practices, fraud, waste, or reprisal for raising a concern.

e. Imminent Danger Condition/Concern. Any condition or practice in any workplace that creates a danger that could reasonably be expected to cause death or serious physical harm immediately or before the onset of such danger could be eliminated through the normal procedural mechanism.

f. Intimidation. Any action taken by coworkers or supervisors against or toward an employee to cause that employee to cease engaging in protected activities; to be fearful of engaging in protected activities; to otherwise be afraid for his or her safety, reputation, or job security as a result of having identified concerns about any aspect of DOE facilities or operations.

g. Investigation. An inquiry conducted by or on behalf of an ECPs office for the purpose of evaluating and resolving a concern, usually involving interviews, inspection of relevant documents, sites, or equipment, and an evaluation of practices being followed.

h. Referral of a Concern. Transmittal of an employee concern to another organization or process for investigation or resolution, with the results of the investigation or resolution attempts being reported to the ECP manager within a specified time period with recommended resolution including corrective actions.

i. Reprisal. Any action taken against an employee in response to, or in revenge for, the employee having raised, in good faith, reasonable concerns about any aspect of DOE-related operations. Reprisals against contractor employees may lead to the imposition of penalties under the Price-Anderson Amendments Act of 1988 (Pub. L. 100-49, August 20, 1988), implemented by DOE under 10 CFR Part 820 (Part 820). Pursuant to Part 820, to the extent a reprisal by a DOE contractor results from an employee's involvement in matters of nuclear safety in connection with a DOE nuclear activity, the reprisal could constitute a violation of a DOE Nuclear Safety Requirement.

j. Resolution of a Concern. Actions taken and decisions made in response to an employee concern by verifying the concern, establishing plans to correct identified deficiencies, correcting the deficiencies, or determining that the concern is not substantiated and no corrective action is required.

k. Transfer of a Concern. Communication of a concern by the ECP office to an office with subject-matter responsibility or expertise pursuant to which that office will address the concern with the concerned employee.

8. CONTACT. Office of Economic Impact and Diversity, Office of Employee Concerns, 202-586-6530.

BY ORDER OF THE SECRETARY OF ENERGY:

FRANCIS S. BLAKE
Deputy Secretary

ATTACHMENT 1

CONTRACTOR REQUIREMENTS DOCUMENT

DEPARTMENT OF ENERGY EMPLOYEE CONCERNS PROGRAM

In support of the effective implementation of the Department of Energy (DOE) Employee Concerns Program (ECP), contractors are required to—

- assist DOE in the resolution of employee concerns in a manner that protects the health and safety of both employees and the public and ensures effective and efficient operation of DOE-related activities under their jurisdiction;

- ensure that contractor and subcontractor employees are advised that they have the right and responsibility to report concerns relating to the environment, safety, health, or management of DOE-related activities; and

- cooperate with assessments used to verify that they have acted to minimize, correct, or prevent recurrence of the situation that precipitated a valid concern.

DOE G 442.1-1

02-01-99

DEPARTMENT OF ENERGY EMPLOYEE CONCERNS PROGRAM GUIDE

OFFICE OF ECONOMIC IMPACT AND DIVERSITY

Distribution:
All Departmental Elements

Initiated By:
Office of Economic Impact and Diversity
Office of Employee Concerns

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1. PURPOSE OF THE EMPLOYEE CONCERNS PROGRAM

The Department of Energy (DOE) recognizes that free and open expression of DOE Federal and contractor and subcontractor employee concerns is essential to safe and efficient accomplishment of DOE's missions. DOE employees and any contractor or subcontractor fulfilling DOE's mission have the right and responsibility to report concerns relating to the environment, safety, health, or management of Department operations. The Employee Concerns Program (ECP) is designed to—

- encourage open communication;
- inform employees of the proper forum for consideration of their concerns;
- ensure employees can raise issues without fearing reprisal;
- address employee concerns in a timely and objective manner; and
- provide employees an avenue for consideration of concerns that fall outside existing systems.

2. DEFINITIONS

Alternative Dispute Resolution. A variety of processes used to resolve disputes through use of a neutral third party in an attempt to avoid judicial or administrative litigation. Forms of alternative dispute resolution include mediation, partnering, ombudsmanship, neutral evaluation, nonbinding arbitration, mini-trial, and binding arbitration.

Concern Review Panel. A group that is brought together to evaluate the merits of a concern. It can be made up of representatives of employees, supervisors, managers, the ECP office, human resources, outside experts, consultants, or stakeholders. A panel may be used to provide program expertise; assist in fact finding; evaluate specific concerns for which there are either unique circumstances or for which there are no previously established evaluation channels; and to recommend resolutions and propose corrective actions.

Confidential Concern. A concern submitted by an employee who wishes to have his or her identity protected from all persons except the ECP staff and those with a need to know.

Confidential Source. A person who provides information to an ECP representative and requests that his or her identity not be revealed.

Differing Professional Opinion. An opinion related to a policy or practice that (1) differs from previous management decisions, stated positions, or established policies or practices; (2) in the opinion of the employee, has not been adequately considered; and (3) if not adopted, has a

reasonable probability of having significant negative impact on the activity in question with respect to safety, efficiency, or quality.

Employee. Any person working for DOE or a DOE contractor or subcontractor on a DOE project.

Employee Concern. A good faith expression by an employee that a policy or practice of DOE or one of its contractors or subcontractors should be improved, modified, or terminated. Concerns can address issues such as health, safety, the environment, management practices, fraud, waste, or reprisal for raising a concern.

Employer. DOE, a contractor, or a subcontractor working on a DOE project.

Harassment. In the context of the ECP, an action taken or condoned by an employer against or toward an employee to bother, belittle, humiliate, or impede that employee in his or her work environment, relationship with others, or job performance because the employee reasonably and in good faith raised a concern. Harassing actions can include, but are not limited to, threatening, restraining, coercing, blacklisting, mocking, humiliating, or isolating an employee.

Intimidation. Any action taken by coworkers or supervisors against or toward an employee to cause that employee to cease engaging in protected activities; to be fearful of engaging in protected activities; or to otherwise be afraid for his or her safety, reputation, or job security as a result of having identified concerns about any aspect of DOE activities or operations.

Investigations. An inquiry conducted by or on behalf of an ECP office, for the purpose of evaluating and resolving a concern, usually involving interviews, inspection of relevant documents, sites, or equipment, and an evaluation of practices being followed.

Protected Activities. Activities such as raising concerns or otherwise making disclosures protected under law, regulations, or legal precedent of information related to DOE operations, which the individual reasonably and in good faith believes is evidence of unsafe, unlawful, fraudulent, or wasteful practices.

Referral of a Concern. Transmittal of an employee concern to another organization or process for investigation or resolution, with the results of the investigation or resolution attempts being reported to the ECP manager within a specified time period with recommended resolution including corrective actions.

Resolution of a Concern. Actions taken and decisions made that respond to the concern by verifying the concern and establishing plans to correct identified deficiencies, correcting the deficiencies, or determining that the concern is not substantiated and that no corrective action is required.

Reprisal. Any action taken against an employee in response to, or in revenge for, the employee having raised, in good faith, reasonable concerns about any aspect of DOE-related operations. Reprisals against contractor employees may lead to the imposition of penalties under the Price Anderson Amendments Act of 1988 (Pub. L. 100-49, August 20, 1988), implemented by DOE under 10 CFR Part 820 (Part 820). Pursuant to Part 820, to the extent a reprisal by a DOE contractor results from an employee's involvement in matters of nuclear safety in connection with a DOE nuclear activity, the reprisal could constitute a violation of a DOE Nuclear Safety Requirement.

Self-Assessment. A quantitative or qualitative method of collecting and analyzing data by the ECP with the goal of detecting trends that are not readily apparent and that warrant corrective measures.

Transfer of a Concern. Transmittal of a concern by the ECP office to an office with subject matter responsibility or expertise pursuant to which that office will address the concern with the concerned individual.

3. SCOPE OF THE ECP

Under the ECP, DOE, contractor, or subcontractor employees may report concerns to Headquarters and field element ECPs regardless of the nature of the issues raised. DOE O 442.1 requires that employees be encouraged to first seek to resolve concerns with their first-line supervisors or use established concern or complaint resolution systems. If these systems are unknown or unavailable, or have not dealt, or cannot deal, effectively with a concern, ECP personnel can assist concerned employees in determining which processes could be used to evaluate and resolve their concerns. This may result in the ECP office facilitating resolution, referring or transferring the concern, or investigating the concern itself. The ECP is intended to *supplement*, not replace, existing processes designed to address concerns and resolve disputes.

ECP personnel should familiarize themselves with existing concern resolution processes available to employees for all types of concerns. Some employee concerns may involve issues that are subject to review under formal programs established by law, rule, or regulation; these programs may require employees to file their concerns, complaints, or allegations with a particular office within an established time frame. To the extent practicable, ECP personnel should inform concerned employees of the existence of other administrative systems available to review their concerns and of the time limits within which employees must file those concerns or allegations. Concerned employees are ultimately responsible for pursuing their rights under existing programs. ECP personnel should document employees' decisions to resolve their concerns informally with ECP assistance rather than to pursue formal action. Receiving assistance from the ECP does not discharge the concerned employee's obligation to meet the filing requirements of other programs. ECP personnel are not expected to advise employees concerning judicial or legal remedies available outside the ECP, beyond indicating that certain statutes may apply to the situation.

4. RESPONSIBILITIES

Managers and supervisors are responsible for establishing open communications to enable employees to raise concerns and to address the concerns of employees under their supervision in a manner that protects the health and safety of employees and the public and ensures the efficient operation of DOE programs. This responsibility must be carried out in a manner that fosters the free flow of information without employees being subjected to reprisal for raising concerns.

Employees are responsible for reporting conditions that adversely affect the quality or safety of DOE operations and for identifying and preventing harassment and intimidation of coworkers.

5. CONCERNS PROCESSING

5.1 ALTERNATIVES FOR PROCESSING CONCERNS

Depending on the jurisdiction and resources of the ECP office, employee concerns generally are processed in one of the following ways:

- investigated or otherwise evaluated through the ECP, in coordination with DOE or external offices when required;
- referred to other offices or programs and tracked by the ECP until they are resolved (referral of a concern);
- transferred to another DOE or contractor organization with jurisdiction over the issues, when those issues are outside the scope of the ECP (transfer of a concern): or
- closed.

The ECPs retain a role in processing referred concerns (i.e., offices report back to the ECP with respect to their findings). When a concern is transferred, it is closed and becomes a matter to be dealt with by the concerned employee and the office to which the concern was transferred or to which the employee submits the concern.

Concerns can be referred or transferred to organizations either inside or outside DOE. For example, the ECP office may refer or transfer a concern to a manufacturer of equipment being used in response to an employee concern that involves a technical question related to equipment specifications and its safe use under certain conditions. Threats of physical violence, including death threats, can be transferred within DOE to the Office of Inspector General or externally to the Federal Bureau of Investigation, local law enforcement, or contractor protection services.

5.1.1 ECP Facilitation of Concern Resolution

If an employee wishes to seek informal resolution through the auspices of the ECP office rather than file a complaint through other available means, and the concern involves issues ECP personnel are not precluded from addressing, ECP personnel may work with the employee, managers, and program officials on an informal basis to resolve the concern.

5.1.2 Referral of Concerns

The ECP manager may refer the employee concern to another organization or authority for analysis and identification of any possible required remedial action. In most cases, the ECP manager requests a brief report detailing the scope and nature of any investigation or evaluation conducted, findings and conclusions, and when appropriate, a recommended resolution and corrective actions. The person, office, or organization assuming responsibility for the corrective actions should be specified. As provided in DOE O 442.1, unless otherwise agreed to by the employee, an organization other than that of the employee's immediate supervisor must conduct the investigation.

The ECP office should request a response within 30 days of the referral. Requests to extend the 30-day period should be sent to the ECP office and documented. The ECP office may provide a status report to the concern originator if the investigating entity has not responded within the 30-day time frame. The ECP manager should review the investigative report for adequacy and, in the case of substantiated concerns, advise appropriate management officials within the field and/or Headquarters offices of any findings and recommendations. To ensure timely compliance with DOE requirements, the ECP manager/facilitator should immediately notify appropriate management officials of investigative results in cases that have significant potential to (1) affect public, employee, facility, or environmental safety or (2) create programmatic impact or negative DOE publicity.

5.1.3 Transfer of Concerns

Certain concerns, based on their type or complexity, may best be reviewed and resolution sought by offices other than the ECP. Concerns can be transferred to organizations either inside or outside DOE. Outside review of an employee concern may be *required* if it involves allegations of criminal wrongdoing, claims of medical disability for which benefits are sought, concerns related to the application of provisions of collective bargaining agreements, or violations of employee rights under labor statutes. Whenever possible, ECP personnel should provide the concerned employee with a specific point of contact in the office or program to which the concern was transferred. Concerns are closed by the ECP when transferred. Concerns may be monitored after being transferred, but there is not a requirement to do so.

5.1.4 Investigation of Concerns by the ECP

The individual assigned responsibility for investigating an employee concern may, in most cases, enter and inspect places and records, interview employees with knowledge of the issues, inspect relevant documents, sites, or equipment, and obtain other information deemed necessary. Contractors should cooperate fully with the investigator in making available employees and all pertinent evidence, including records, consistent with their contractual obligations to DOE.

5.2 INITIAL COLLECTION OF CONCERN INFORMATION

When a concern is received, the person receiving the concern attempts to obtain as much information as possible from the concerned employee. At a minimum, the following information is obtained when possible:

- full name of the concerned employee;
- complete mailing address;
- telephone number where the employee can be reached;
- position or relationship to the employer (DOE or contractor);
- nature of the concern;
- the availability of employer processes to address the concern;
- previous attempts to have the concern addressed within the concerned employee's organization; and
- whether the concerned employee is requesting confidentiality.

ECP personnel create a written record, preferably signed by the concerned employee, reflecting the scope and substance of the concern. If the concerned employee declines to provide the requested information, the individual receiving the concern attempts to establish the reason but does not discourage the employee from using the process by demanding additional detail.

6. PROGRAM ACCESS AND TRACKING

6.1 ANNUAL NOTIFICATION

The success of an ECP office depends in large part on the visibility of management support of employee freedom to raise concerns without the fear of retaliation. To ensure this visibility, the head of the Headquarters program office or field element is encouraged to remind all employees annually of the availability and purpose of the ECP.

6.2 POSTERS

The ECP office should place posters in conspicuous locations to inform employees of the existence of the ECP, the ECP office telephone number, and the availability of an ECP 24-hour access hot-line.

6.3 HOT-LINE ACCESS

The ECP provides 24-hour hot-line access to the program. The listing of telephone numbers and any E-mail address in the DOE telephone book and on posters serves to advise employees of the availability of, and means to access, the ECP.

6.4 EMPLOYEE CONCERNS TRACKING SYSTEM

Information regarding employee concerns is maintained in a tracking system. Because of the nature of the information, it should be maintained according to existing rules applicable to sensitive materials as well as the Privacy Act. The tracking system includes the following information, to the extent practicable:

- assigned employee concern number;
- date and time of receipt of the concern;
- when a concern involves a safety or health condition, whether the concern meets the criteria for an imminent danger condition concern, a serious condition concern, or an other-than-serious condition concern in accordance with Section 8 below;
- method of receipt (e.g., walk-in, mail, hot-line, telephone);
- category of the concern (e.g., environmental, safety, security, fraud, waste, abuse, equal employment opportunity, quality, management, workplace violence, etc.);
- a brief description of the concern;
- date of receipt acknowledgment to the concern originator;
- date of referral, if the concern is referred to another organization, and the point of contact identified to the employee;
- date of transfer of the concern to another organization or authority and the point of contact identified to the employee;
- name of the investigative organization;

- date the investigative responsibility was assigned;
- date response to referral is expected;
- date the investigation results were received;
- whether the concern was substantiated, partially substantiated, or unsubstantiated;
- disposition/resolution, including any corrective action(s) taken or anticipated;
- date of resolution;
- date the originator was notified of the resolution; and
- date the ECP manager closed the concern.

7. CONFIDENTIALITY

Confidentiality is a cornerstone of an effective ECP and the investigation of concerns. Situations exist in which concerned employees are afraid to contribute information to investigators for fear of reprisal or intimidation by coworkers or supervisors. Recognizing that some individuals will come forward only if they believe their identities will not be disclosed, the protection of confidential sources is a significant factor in ensuring the voluntary flow of information. During the investigation or evaluation of a concern, it may also be necessary to grant confidentiality to employees other than the concerned employee who also provide information. As such, ECPs must provide confidentiality to the greatest extent possible to meet a concerned employee's or a witness's request, but concerned individuals must be informed of limitations in providing confidentiality in evaluating and attempting to resolve certain types of concerns. Confidentiality cannot be protected if maintaining that confidentiality puts at risk the health and safety of the workers or the public. In addition, the extent to which confidentiality can be granted depends on factors such as the following:

- inherent impediments to an investigation thoroughness due to granting confidentiality;
- the extent to which a particular employee may be identified with the concerns as the result of previous activities;
- the extent to which the concerns are being resolved through litigation; and
- the ability to protect the individual's identity since the employee concerns records may be subject to disclosure under the Privacy Act or the Freedom of Information Act.

Even when the ability to grant confidentiality is limited, ECP personnel and individuals assigned responsibility for investigating, evaluating, or resolving a concern may only reveal the identity of the concerned employee on a need-to-know basis.

ECP personnel should request the following information from the concerned employee to determine whether confidentiality can be maintained once granted:

- Has the individual provided the information about the concern to anyone else, and is the employee's pursuit of a resolution of the particular concern common knowledge to other employees?

- Why does the individual desire confidential source status (i.e., what would be the consequences if his or her identity were revealed)?

- Does it appear that the individual who caused the condition or committed the violation that is the subject of the concern is likely to be subject to civil or criminal prosecution?

- Is the nature of the concern personal to the concerned employee to such a degree that the investigation of the concern would readily identify the concerned employee as the source of the concern?

Confidentiality will not be extended to any person who in the course of his or her employment, or due to the nature of his or her position, is required to provide such information. The inspector or investigator will advise each person to whom confidentiality is granted that such grant of confidentiality is conditional, not absolute.

8. PRIORITY DESIGNATION OF OCCUPATIONAL HEALTH AND SAFETY CONCERNS

Concerns are designated for processing in accordance with the criteria established by the Office of Environment, Safety and Health (ES&H). An employee concern involving an imminent danger condition/concern or serious condition/concern will be immediately brought to the attention of the appropriate line manager and/or the ES&H program office for evaluation and action. The ECP must ensure that an initial determination of the health and safety significance of the concern is performed. Priorities for resolution must be established based on determination of the risk of the concern. Generic guidance for safety significance is provided below; however, for occupational safety and health concerns, additional classifications follow.

- **Imminent danger condition/concern.** Any condition or practice in any workplace that creates a danger that could reasonably be expected to cause death or serious physical harm immediately or before the onset of the danger could be eliminated through the normal procedural mechanism. ES&H requires that such concerns be investigated within 24 hours.

- **Serious condition/concern.** A hazard, violation, or condition that causes a substantial probability that death or serious physical harm, property loss, and/or environmental impact could result. ES&H requires that such concerns be investigated within 3 working days.

- **Other-than-serious condition/concern.** Hazards, violations, or conditions that may not result in death or serious physical harm, property loss, and/or environmental impact but may have a direct and immediate relationship to worker safety and health or the environment. ES&H requires that such concerns be investigated within 20 working days.

The following ES&H guidelines are intended to be illustrative, not all-inclusive, of criteria that should be used to assess the significance of the concern. The degree to which a concern involves an imminent danger or condition is judged by determining whether the concern involves any of the following criteria:

- Initiation of work in the face of identified environmental, safety, or health concerns that could result in an immediate or near-term threat to the safety or health of the public or workers.

- Continuation of operations in the face of inoperable or deficient environmental, safety, and health equipment, monitoring instrumentation, or systems.

- Violations of the Price-Anderson Amendments Act enforcement authority; criminal acts involving nuclear safety matters (e.g., falsification of facility logs and records); willful violations of regulations, DOE directives, operating procedures, or specifications; or other criminal acts.

- Deficiencies observed in the normal reporting system (e.g., lack of notification of environmental, safety, or health issues and events of significance to proper authorities as required by DOE Orders, procedures, or Federal and State environmental laws).

- Collection, dissemination, and recording of inaccurate or falsified environmental, safety, or health related data.

- Material misrepresentations to inspectors, auditors, or reviewers when performing official duties.

9. CLOSING A CONCERN

DOE O 442.1, paragraph 4c, specifies the bases for closing a concern. These include:

- the concern has been investigated; necessary corrective actions have been identified and the office responsible for taking the corrective action has accepted jurisdiction over the matter;

- the concern has been investigated and no corrective action is deemed necessary;

- the subject matter of the concern is outside the scope of the ECP and the concern has been transferred to another organization with jurisdiction over the subject matter;

- ECP personnel have advised an employee raising a concern that is outside the scope of the ECP of available means to have the concern addressed, if direct transfer of the concern to another organization is not appropriate; and

- the ECP determines that the issues are frivolous or too general to investigate.

10. CORRECTIVE ACTIONS

Assessments by offices with responsibility for the operation or oversight of the program will be used to verify that actions have been taken by DOE and DOE contractors to minimize, correct, or prevent recurrence of the situation(s) that precipitated a valid concern. To the extent practicable, ECP offices should monitor actions taken on concerns, even though responsibility for action rests with other offices.

11. ALTERNATIVE DISPUTE RESOLUTION

Alternative dispute resolution processes are effective mechanisms for resolving concerns. These processes can be used to resolve differences prior to conducting reviews or investigations since they provide means for parties to express their differences with the aid of a third party. Mediation and concern review panels are examples of alternative dispute resolution processes.

Mediation. Mediation has been shown to be an effective and efficient means for resolving disputes that range from interpersonal differences to complex business disputes. Various resources are available for mediation dispute resolution, including the use of mediators from the Federal Mediation and Conciliation Service or other Government agencies or private individuals who serve as mediators. ECP managers who need assistance in arranging for mediation services can call on the Headquarters Office of Employee Concerns, which works with the Director of the Office of Dispute Resolution, to make mediation services available in a timely manner.

Concern Review Panels or Differing Professional Opinion Panels. Panels can be designated by the Program Secretarial Officer, the head of the field activity, or ECP managers working with the concerned employee and appropriate offices. Membership on the panels, when possible, should be voluntary and for a specific time frame. Panels should have the ability to provide input to the action plan, review the concern, and make specific recommendations addressing each concern. Employers may also establish panels to deal with concerns raised by employees.

Based on the nature of the concern, panels may be composed of employees, supervisors, managers, representatives from human resources, outside experts or stakeholders, and someone from the ECP office. Panels may be convened to review concerns involving, for example, issues

relating to health, safety, or quality; allegations of harassment, intimidation, or retaliation for protected activities; issues requiring external expertise and resources for evaluation; or concerns that cross organizational or program boundaries.

12. QUARTERLY AND ANNUAL REPORTS

The ECP manager provides the head of his or her organization at least quarterly a statistical report of concerns received, closed, or remaining unresolved during the last quarter and sends copies to appropriate field and Headquarters organizations. Anonymity and confidentiality of concerned employees are protected by limiting access to quarterly status report information and because reports generated for the general public or other external organizations are statistical summaries only.

The ECP prepares annual reports on a calendar year basis. The ECP manager reviews the quarterly reports for lessons learned and possible adverse trends, which the ECP office will include in its annual report. The ECP disseminates information from concern reports to DOE organizational elements or DOE personnel on a need-to-know basis as directed by the office managers responsible for the employee concerns function.

13. RECORDS

Federal records cannot be destroyed unless authorized by the Archivist of the United States, National Archives and Records Administration (NARA). Authorities are found in the General Records Schedule of the Government, as issued by NARA, and in NARA-approved DOE records disposition schedules (Standard Forms 115). Should any or all ECP records not be "covered" by authorized records disposition schedule, the responsible ECP manager must seek NARA authorization (a records disposition schedule) through the cognizant local records officer in liaison with the Departmental Records Officer.

Depending on the nature of the employee concerns records maintained, they may be subject to the provisions of the Privacy Act of 1974. The Privacy Act defines "record" as "any item, collection, or grouping of information about an individual that is maintained by an agency, including, but not limited to, his education, financial transactions, medical history, and criminal or employment history and that contains his name, or the identifying number, symbol, or other identifying particular assigned to the individual...." ECP records are subject to release pursuant to requests made pursuant to the Freedom of Information Act. Requests for records under Freedom of Information Act are subject to exceptions to release, including unwarranted invasions of privacy.

14. EMPLOYEE CONCERNS PROGRAM ORIENTATION FOR MANAGERS AND EMPLOYEES

ECP orientation is necessary to develop open communication in which employees feel free to raise concerns without the threat of reprisal. DOE, contractor, and subcontractor management have an obligation and a responsibility to address employee concerns and to resolve these concerns in a manner that will protect the health and safety of employees and the public and ensure the effective and efficient operation of programs under their jurisdiction. Orientation materials and/or training should make it clear that an employee may, at any time and for any reason, contact his or her employer's ECP, if one exists; the DOE ECP; or other Federal or State agencies responsible for oversight of DOE facilities to find out how to address various types of employee concerns.

The ECP should have information available about the appropriate avenues for addressing a wide variety of issues, including those for which formal review processes exist, such as environmental, safety, health, fraud, waste, abuse, equal employment opportunity, and whistleblower reprisal issues. Information should be available as to how an employee can address concerns through such organizations as the Nuclear Regulatory Commission, the Equal Employment Opportunity Commission (or State or local human rights offices), the Environmental Protection Agency, and the Department of Labor if they prefer to bring their concerns to the attention of these organizations rather than using DOE or contractor reporting systems or the chain of command.

15. SELF-ASSESSMENT

The ECP manager conducts annual self-assessments to determine ways to enhance the effectiveness of the ECP. Customer satisfaction surveys are a key to receiving realistic feedback on program operations and should be a part of self-assessments.

ENCLOSURE

#8

DOC.20040225.0002

Office of Civilian Radioactive Waste Management QA: N/A

PROCEDURE

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT CONCERNS PROGRAM

AP-32.1

Revision 1 ICN 0

Effective Date: March 1, 2004

Preparer: J. F. Streeter — Date: 2/23/04

Approval: W. John Arthur, III — Date: 2/23/04

W. John Arthur, III
Deputy Director
Office of Civilian Radioactive Waste Management
Office of Repository Development

1.0 PURPOSE

This procedure describes the Office of Civilian Radioactive Waste Management (OCRWM) Concerns Program (OCP) process. The OCP is an important element of the Safety Conscious Work Environment (SCWE) and is designed to complement other SCWE efforts to ensure that employees feel free to raise concerns without fearing any form of reprisal. The OCP process provides employees an alternative method to have their concerns independently, impartially and confidentially evaluated, and is intended to supplement, not replace, other established processes designed to address concerns. Employees are encouraged to first seek resolution of concerns through their first-line supervisors and chain of command, or use other existing processes designed to address specific types of concerns.

2.0 APPLICABILITY

This procedure applies to all personnel, Federal and contractor, working on OCRWM activities.

Use of the OCP does not affect an individual's right to pursue concerns at any time through any agency or office (such as the Department of Energy (DOE), Department of Labor, Nuclear Regulatory Commission, DOE Office of Inspector General), and use of the OCP does not relieve a person of any filing or other statutory / regulatory process requirements.

Some concerns may be outside the scope of the OCP. For example, there are established processes to address concerns involving subjects such as waste, fraud and abuse; equal employment opportunities; security; collective bargaining agreements; and personal and personnel matters. However, if established processes are unknown or unavailable, or have not dealt or cannot deal effectively with a concern, the OCP will be available to assist employees in determining which processes could be used to address the concern. In such instances this may result in the OCP facilitating employee use of another process, referring or transferring the concern, or evaluating the concern itself.

3.0 OTHER DOCUMENTS NEEDED/REFERENCES

- Privacy Act of 1974, Public Law 93-579, (5 U.S.C. 552a), as amended
- DOE 0442.1A, Employee Concerns Program
- DOE/RW-0555, Program Manual
- POL-RW-2002-001, Safety Conscious Work Environment Policy
- AP-17.1Q, Records Management
- AP-16.1Q, Condition Reporting and Resolution

4.0 RESPONSIBILITIES

4.1 The Director, OCRWM is responsible for designating the management position responsible for developing and implementing the OCP. The Director, OCRWM has designated the Deputy Director, Office of Repository Development (ORD), as the OCRWM senior manager responsible for developing and implementing the OCP which is an OCRWM-wide program.

4.2 The Deputy Director, ORD, is responsible for the approval of this procedure; for providing adequate resources and training for effective implementation; and for using management assessment results to verify the adequacy and implementation of the OCP and improve its performance.

4.3 The Deputy Director, ORD; Deputy Director, Office of Strategy and Program Development (OSPD); or Director, OCRWM are responsible for considering appeals of evaluations of concerns within their assigned roles and organizational responsibilities.

4.4 The Manager, OCP, is responsible for the preparation, change, maintenance, and implementation of this procedure.

4.5 The Manager OCP is responsible for periodically reporting on OCP activities to the Deputy Director, ORD, including Lessons Learned, possible adverse trends, and recommended actions to improve performance of the Yucca Mountain Project.

4.6 All management personnel, Federal and contractor, working on OCRWM activities are responsible for supporting the OCP in its evaluations of concerns and implementation of needed corrective actions.

4.7 The following organizations or positions are responsible for activities identified in Section 5.0 of this procedure:

a. Concerned Individual
b. OCP Representative
c. Director, OCRWM
d. Deputy Director, ORD
e. Deputy Director, OSPD
f. Manager, OCP

5.0 PROCESS

Acronyms and Abbreviations used in this procedure are defined in Attachment 1, Acronyms and Abbreviations. Terms used in this procedure are defined in Attachment 2, Definitions.

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5.4 RECONSIDERING CONCERN EVALUATIONS 6
5.5 APPEALING CONCERN EVALUATIONS 6

5.1 INITIATING CONCERNS

NOTE: Concern Initiation Forms are available in work areas, and on the Intranet. Additionally, concerns may be submitted via: Telephone, Hotline, Fax, Email, Face-to-face, US Mail, or Exit interviews.

Individuals may discuss information with OCP representatives before making a decision on whether to submit a concern to the OCP for evaluation. Such discussions are encouraged.

NOTE: Maintaining confidentiality is a cornerstone of the OCP and is a critical factor in establishing and maintaining respect for and use of the OCP process. The OCP is designed and will be administered in a manner that maintains an employee's confidentiality, when requested, to the maximum extent practicable.

Individuals may also submit concerns to the OCP anonymously.

Concerned Individual (CI)

[1] **Submit** a concern to the OCP, **AND ensure** that sufficient specific information is provided to enable the OCP to perform an evaluation that directly and effectively addresses the matter.

OCP Representative

[2] **Acknowledge** promptly to the CI the OCP receipt of the concern.

5.2 EVALUATING CONCERNS

OCP Manager

[1] IF the concern is outside the scope of the OCP,

THEN **assist** the CI in determining which processes could be used to address the concern.

OCP Representative

[2] IF the CI desires confidentiality,

THEN **inform** the CI of any confidentiality limitations.

[3] **Reach** agreement with the CI regarding interim feedback during the OCP evaluation process, **AND provide** that feedback at the agreed upon intervals.

[4] Inform the CI of the timeliness goal for addressing the concern.

OCP Manager

[5] IF the concern indicates a potential imminent danger condition OR indicates a potentially reportable condition to a regulatory agency,

THEN **notify** senior line management having jurisdiction over the subject

matter in question.

[6] **IF** the concern indicates a potential Condition Adverse to Quality (CAQ),

THEN ensure a Condition Report is processed in accordance with AP-16.1Q.

[7] **Ensure** that personnel involved in the OCP evaluation process have the necessary expertise to evaluate the issues, and their involvement does not involve a potential conflict of interest.

OCP Representative

[8] **Conduct** the OCP evaluation of the concern in a timely manner.

[9] **Document** the evaluation of the concern, **AND file** the evaluation results in the concern file.

OCP Manager

[10] **Approve** the results of the OCP evaluation.

OCP Representative

[11] **Brief** the CI on the results of the evaluation.

[12] **Consider** any comments offered by the CI, **AND inform** the CI of the results of the consideration, **AND file** the results of the consideration in the concern file.

OCP Manager

[13] **IF** corrective actions are necessary,

THEN establish with responsible management the details of those actions and schedules for completion, **AND file** the details of those actions in the concern file, **AND track** those actions to completion.

5.3 CLOSING CONCERNS

[1] **IF**

- The concern has been evaluated; necessary corrective actions have been identified; the office responsible for taking the corrective actions has accepted jurisdiction; and the corrective actions have been completed or documented in a tracking system.

  OR

- The concern has been evaluated and no corrective action is deemed necessary.

  OR

The subject matter of the concern is outside the scope of the OCP and the concern has been transferred to another organization with jurisdiction over the subject matter.

OR

- The OCP determines that the issues are too general to evaluate.

THEN **inform** the CI, AND **close** the concern.

5.4 RECONSIDERING CONCERN EVALUATIONS

CI

[1] IF the CI is dissatisfied with the OCP evaluation process or results,

THEN the CI may **provide** the reasons for the dissatisfaction to the OCP Manager.

OCP Manager

[2] **Consider** any comments offered by the CI, AND **inform** the CI of the results of the consideration, AND **file** the results of the consideration in the concern file.

5.5 APPEALING CONCERN EVALUATIONS

CI

[1] IF a CI is still dissatisfied with the OCP evaluation process or results, or feels that an unresolved concern continues to exist,

THEN the CI may **appeal** the OCP evaluation to the OCRWM senior manager (Deputy Director, ORD; Deputy Director, OSPD; or Director, OCRWM) having jurisdiction over the related roles and responsibilities.

Deputy Director, ORD; Deputy Director, OSPD; or Director, OCRWM

[2] **Consider** appeal by the CI, AND **communicate** the results of the consideration to the CI and the OCP.

OCP Manager

[3] **File** the results of the consideration in the concern file.

6.0 RECORDS

The records listed in Subsections 6.2 shall be retained by OCP. This retention is to assure the identity of each CI is protected consistent with the employee's request for confidentiality and the provisions of the Privacy Act.

Records shall be dispositioned in accordance with AP-17.1Q, OCP file plan instructions, and approved DOE Records Disposition Schedules.

6.1 QA RECORDS

None

6.2 NON-QA LONG-TERM RECORDS

Official Concerns Program Files

Exit Forms and Exit Documentation

Records Documenting Concerns That Do Not Develop Into Official Cases

6.3 NON-QA SHORT-TERM RECORDS (THREE YEARS OR LESS RETENTION)

None

7.0 ATTACHMENTS

1. Attachment 1, Acronyms and Abbreviations
2. Attachment 2, Definitions
3. Attachment 3, Change History

Acronyms and Abbreviations

CAQ	Condition Adverse to Quality
CI	Concerned Individual
DOE	U.S. Department of Energy
OCP	Office of Civilian Radioactive Waste Management Concerns Program
OCRWM	Office of Civilian Radioactive Waste Management
ORD	Office of Repository Development
OSPD	Office of Strategy and Program Development

Definitions

Concern–An expression by a person that a policy or practice of DOE or one of its contractors or subcontractors should be improved, modified, or terminated. Concerns can address issues such as health, safety, quality, the environment, management practices, or reprisal for raising a concern.

Concerned Individual–A person expressing a concern through the OCP.

Conflict of Interest–A situation in which the person responsible for evaluating a concern could be associated, either directly or indirectly, with that concern.

Imminent Danger Condition–Any condition or practice in any workplace that creates a danger that could reasonably be expected to cause death or serious physical harm immediately or before the danger could be eliminated through the normal procedural mechanism.

Evaluation-An inquiry conducted by or on behalf of the OCP for the purpose of addressing a concern. The details of evaluations will vary depending on the nature of concerns. Evaluations range from discussions with personnel to conducting investigations. If an investigation is conducted, it will frequently involve interviews; inspection of relevant documents, sites, or equipment; and assessment of practices being followed.

Referral of a Concern-Transmittal of a concern by the OCP to another organization or process for evaluation with the results of the evaluation being provided to the OCP for communication to the CI.

Reprisal-Any action taken against an employee in response to, or in revenge for, the employee having raised a concern about any aspect of DOE-related operations.

Transfer of a Concern–Transmittal of a concern by the OCP to an office with subject-matter responsibility or expertise pursuant to which that office will address the concern with the concerned employee.

Change History

Revision Number	Interim Change No.	Effective Date	DESCRIPTION OF CHANGE
1	0	03/01/2004	Complete revision to make it consistent with DOE Order 0442.1A, "Department of Energy Concerns Program", and address CR 191.
0	1	02/17/1997	ICN to eliminate reference to QAP 16.1, *Corrective Action*, that has been canceled. Pages affected are 5, 6, 10, 12, and 14.
0		05/24/1995	Initial Issue – Incorporates and supersedes QAAP 1.2, *OCRWM Quality Concerns Program*, Rev. 0. Incorporates AP-6.18, *Resolutions of Environment, Safety and Health Concerns*, and incorporates editorial changes which change the Program's title.

DETAILED PROCESS INSTRUCTIONS

OCRWM CONCERNS PROGRAM

Revision 0

Approval: _____ _____

Julie A. Goeckner
Manager
OCRWM Concerns Program

Date

1.0 PURPOSE

This Detailed Process Instructions (DPI) establishes the responsibilities, processes and actions taken by the OCRWM Concerns Program (OCP) to process and address Federal or contractor employee concerns in accordance with AP-32.1, OCRWM Concerns Program. This DPI also provides information and guidance to the OCP staff on training requirements, self-assessments, generating periodic reports, required interfaces, and OCP program awareness.

2.0 APPLICABILITY

This DPI applies to all OCRWM personnel performing activities associated with OCP.

3.0 OTHER DOCUMENTS NEEDED/REFERENCES

- 10 CFR 708, DOE Contractor Employee Protection Program
- 10 CFR 1008, Energy Records Maintained on Individuals (Privacy Act)
- 10 CFR 63.9, Employee Protection
- 29 CFR 24 (211), Procedure For The Handling Of Discrimination Complaints Under Federal Employee Protection Status
- DOE O 442.1A, Department of Energy Employee Concerns Program
- DOE G 442.1-1, Department of Energy Employee Concerns Guide
- AP-5.1Q, Procedure Preparation, Review and Approval
- AP-17.1Q, Records Management
- AP-32.1, Office of Civilian Radioactive Waste Management Concerns Program
- NRC Inspection Procedure 40001, Resolution of Employee Concerns
- Freedom of Information Act
- LP-PM-001 OCRWM Self Assessment Program
- POL-RW-2004-004, Safety-Conscious Work Environment
- POL-YMP-2004-003, Use Of Recording Devices
- NEI 97-05 [Rev.2] – Nuclear Power Plant Personnel-Employee Concerns Program-Process Tools in A Safety Conscious Work Environment

4.0 RESPONSIBILITIES

4.1 The OCP Manager is responsible for the preparation, change, maintenance, and approval of this DPI.

4.2 OCP personnel are responsible for OCP activities identified in this DPI.

5.0 PROCESS

An overview of this process is depicted in the flowchart shown in Attachment 1, OCP Evaluation Process Flowchart. Acronyms and Abbreviations used in this procedure are defined in Attachment 2, Acronyms and Abbreviations. Terms used in this procedure are defined in Attachment 3, Definitions.

Process Outline

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5.1 RESPONSIBILITIES

OCP Manager

[1] Reports to the Associate Deputy Director, Office Of Repository Development (ORD) and acts as the primary contact for the OCP. The OCP Manager, is responsible for the preparation, change, maintenance, and implementation of the OCWRM Concerns Program. **(Ref: AP-32.1)**

[2] Keeps the OCRWM Director and Senior Staff informed on OCP activities including any issues or problems that hinder the effectiveness of OCP, lessons learned, possible adverse trends, and recommended actions to improve performance of the Yucca Mountain project. **(Ref: AP-32.1(4.5))**

[3] Briefs senior managers, as appropriate, on the results of OCWRM Concerns Program activities. Advise appropriate levels of management when actions are either ineffective or not timely in resolving concerns or correcting identified deficiencies. **(Ref: DOE 442.1A(4)(c)(12))**

[4] Maintains interfaces with managers; DOE contractor employee concerns programs; external regulatory bodies that require an employee concerns program; Headquarters Office of Employee Concerns, NRC and labor organizations, as applicable. **(Ref: DOE 442.1A (4) (a) (1) and OA Item # 1)**

[5] Develop OCP implementation documentation and provide to the OCRWM Deputy Director, as appropriate. **(Ref: DOE 442.1A(5)(c)(1))**

[6] Implement the OCP and ensure concerns are processed in accordance with DOE requirements and NRC expectations. **(Ref: DOE 442.1A (5)(c)(2) & NRC Inspection Manual 40001(02.01)(b))**

[7] Maintains administrative, revision, and distribution control of the OCP DPI and associated forms.

[8] Maintain an employee concerns tracking system and a secure filing system consistent with DOE requirements and NRC expectations. **(Ref: DOE 442.1A (5)(c)(4) & NRC Inspection Manual 40001(03.0(a))**

[9] Decide which concerns warrant referral or transfer to another office for further review, or which warrant no further action (including concerns that are deemed to be outside the scope of OCP). **(Ref: DOE 442.1A (5) (c) (5) & (7))**

[10] Ensures that, on receipt, all concerns are logged using a unique file number, maintained in a secure manner, and tracked through resolution and closure. **(Ref: DOE 442.1A (4) (b) (3)**

[11] Assist in evaluation and resolution of employee concerns. **(Ref: DOE 442.1A (5) (c) (6))**

[12] Document that an individual office or organization has accepted responsibility for management actions to minimize, correct, and/or prevent recurrence of deficiencies identified in the process of investigating concerns. **(Ref: DOE 442.1A (5) (c) (8))**

[13] Prepare quarterly and annual reports and review them for lessons learned and possible adverse trends. **(Ref: DOE 442.1A (5)(c)(9))**

[14] Reports HIRD allegations, alleged wrongdoing, and imminent danger conditions to the OCRWM Director and /or appropriate Deputy Director.

[15] Ensures reports and other support documentation relative to concerns are reviewed for sensitive, proprietary, and/or classified information. If classified information/activities are part of a concern, the OCP Manager ensures that concerns are investigated by an individual having the appropriate security clearance level and that the reports are reviewed and appropriately sanitized by an authorized classifier. **(Ref: DOE O 442.1A (4) (b) (9))**

[16] Coordinates with DOE Contracting Officers to determine the existence of contract requirements for the establishment of contractor Employee Concerns Programs and the means and criteria by which such programs will be evaluated. **(Ref: DOE 442.1A (4) (c) (11))**

[17] Escalates concerns through the management chain, as appropriate, to the OCRWM Director if necessary to ensure proper management attention is provided to each concern issue.

[18] Annually designate and document in writing (e-mail or hard copy) a Records Coordinator for OCP consistent with AP-17.1Q, Records Management. **(Ref: AP -17.1Q (5)(1)(1)(2)(a))**

[19] Assures compliance with Policy, POL-YMP-2004-003, "Use of Recording Devices." **(Ref: POL-YMP-2004-003)**

Concerns Program Analyst

[1] Reports to the OCP Manager or Lead Contractor Representative.

[2] Receives and processes concerns as assigned by the OCP Manager in accordance with guidance provided in this DPI.

[3] Conducts intake interviews to ensure the CI provides sufficient detail to identify the issues.

[4] Screens concerns to secure personal information as requested by the CI or as deemed appropriate to maintain confidentiality.

[5] Interfaces with management and employees at all levels within the OCRWM organization, other government agencies, contractor management or other appropriate personnel as necessary to investigate assigned concern.

[6] Participates, as requested, in OCP triage meetings to determine concern classification, category and priority designation.

[7] Prepares concern investigation plan unique to the specific issues in the concern and submits the plan to the OCP Manager for review and approval prior to investigation.

[8] Conducts comprehensive unbiased investigations of employee concerns, documents related interviews, prepares detailed reports, and compiles relevant support material and follow-up documentation.

NOTE: If the CPA identifies issues in the course of an investigation that create a conflict of interest for themselves, the CPA must immediately notify the OCP Manager to determine how best to proceed.

[9] Maintains concern files in accordance with instructions contained in this DPI.

[10] Conducts an analysis and evaluates responses received from Referrals to ensure adequate information has been provided to address the concern. Based on analysis, provides recommendations to the OCP Manager on the adequacy of the response.

[11] Assist the OCP Manager in performing audits/assessments of contractor ECP's, as requested.

[12] Conduct exit interview documentation of departing with personnel in accordance with this DPI.

[13] Demonstrate behavior consistent with SCWE Policy, "POL-YMP-2004-004."

Administrative Assistant

[1] Interface with customers and ensure efficient operation of OCP telephone, hotline and fax systems.

[2] Demonstrate behavior consistent with SCWE Policy, "POL-YMP-2004-004."

[3] Compiles, creates and distributes status reports and performance data as requested by the OCP Manager.

[4] Prepares and maintains a comprehensive records database that includes long-term records archival/retrieval system for OCRWM Concerns Program records.

[5] Maintains appropriate confidentiality and access to information retained in the OCP files.

[6] Maintains a filing system for OCP routine records and a secure filing system for OCP records consistent with DOE requirements. **(Ref: DOE O 442.1A (4)(d)(3) and DOE AP-17.1Q/Rev.3/ICN4)**

[7] Serves as the designated OCP Records Coordinator for records creation, use, maintenance, retention, storage, and disposition of OCRWM OCP records. **(Ref: AP-17.1Q/Rev.3/ICN4 (3)(1)(9))**

[8] Electronically maintains the DPI, OCP forms, OCP correspondence and other documentation. Revises such as requested by the OCP Manager.

[9] Supports exit process, which includes comprehensive database, signing electronic Employee Status Change Notifications (ESCNs), and supplies OCP exit material to OCP Concerns Program Analyst and sends exit material to employees as needed.

[10] Receives all incoming correspondence, date-stamps and distributes to appropriate individual (i.e., OCP Manager or CPA).

5.2 INITIAL CONTACT/CONSULTATION

Concerned Individual

[1] Initiate contact with the OCP to informally discuss concern(s).

Concerns Program Analyst

[2] Inform the CI of available avenues of redress so the CI is able to make an informed decision on whether or not they wish to file a concern. **(Ref: DOE G 442.1A(5)(1)(1))**

NOTE: If the concern indicates an environment, safety, and health (ES&H) or Quality concern that involves potential imminent danger condition, a HIRD condition, a serious condition or a potentially reportable condition to a regulatory agency, the OCP Analyst has a duty to act and will immediately inform the OCP Manager. The OCP manager will then report the condition to the appropriate line manager. **(Ref: DOE 442.1A (b) (7)).**

If a contractor employee believes an adverse action has been taken against them for raising a concern or engaging in other protected activities the CPA must verbally advise them of their right to pursue the issue under 10 CFR 708, "Contractor Employee Protection Plan" and/or 29 CFR 24 (Section 211)"

If a Federal employee believes an adverse action has been taken against them for raising a concern or engaging in protected activities, the CPA must verbally advise the employee of their right to file a complaint with the Merit System Protection Board (MSPB) or Office of Special Counsel (OSC). **(Ref: SCWE Action Plan)**

Concerned Individual

[1] Choose to file a concern with OCP;

OR

[2] Choose to pursue the concerns through other available avenues of redress.

5.3 INITIATE A CONCERN

Concerns Program Analyst

[1] Initiates an intake interview with the CI to further develop information initially provided by the CI. The intake interview is conducted using Attachment 4, "Intake Interview Guideline."

OR

[2] If concern is anonymous document concern as identified below.

NOTE: The Intake Interview Guideline is ONLY a guideline and is not to be completed and included in the OCP file.

Anonymous concerns containing comments or suggestions do not require a formal investigation. Comments/suggestions are forwarded, as deemed appropriate by the OCP Manager, to management.

The CPA must notify the OCRWM Director when a concern directly affects the Office of Deputy Director ORD OCRWM or the concern is against the OCP.

[3] Assign the concern the next available number from the OCP Concerns log and enters the applicable data into the log. **(Ref: DOE 442.1A/4.b.3)**

[4] Prepare Attachment 7, "Concern Summary Form," for each concern identified. This includes, at a minimum, the following: **(Ref: DOE O 442.1A (4) (b)(2))**

- A sanitized concern summary statement.
- A complete description of the condition from the CI's perspective (who, what, where, when, why and how), including any requirements/drivers for those concerns (DOE Orders, regulations, guidelines, etc.).

NOTE: This form documents each concern in sufficient detail. The first part of the form describes in one or two sentences a sanitized version of the concern/issue. The second part of the form is more detailed to permit investigation or other appropriate levels of review, using the notes taken during the intake interview.

Concerned Individual

[1] Review the completed concern statement form(s) and signs the form(s) indicating agreement with the composition of the concern/issue statement(s). The CI's signature is desired, but not required.

NOTE: Except for anonymous concerns, reasons for non-signature are documented in Attachment 6, "Concern Chronology."

Concerns Program Analyst

[1] Discuss confidentiality with the CI, and answers questions regarding Attachment 5, OCRWM Concerns Program Confidentiality Statement. During those discussions the CI is informed of the limitations of OCP's ability to protect confidentiality under certain circumstances. **(Ref: DOE 442.1A (4) (b) (5))**

NOTE: Confidentiality cannot be maintained in certain circumstances. Examples include; a potential for imminent hazard situations; allegations of HIRD, situations where the CI had held discussions with others about the concern, or potential violations of law.

Concerned Individual

[1] Complete Attachment 5, "Confidentiality Statement" form and sign to acknowledge their understanding of the limitations of confidentiality.

Concerns Program Analyst

[1] Inform the CI of the purpose of the data collection, how it will be used and the final records are subject to DOE System of Record 3, "Employee Concerns Program Records" and Exemption 6 of the Freedom of Information Act (FOIA).

[2] Request information regarding why the CI chose to come to the OCP, and whether the CI attempted to have the concern addressed by line management or BSC ECP.

[3] Inform the CI that the OCP Manager will notify OCRWM executive management of the existence of the concern but not the CI's identity.

[4] Establish a method of contact with the CI and feedback intervals that are agreeable.

5.4 INITIAL PROCESSING OF A CONCERN

Concerns Program Analyst

[1] Prepare Attachment 6, "Concern File Chronology," documenting events and communications pertinent to the concern, along with the date of occurrence and the author of the information. Any OCP representative who obtains information associated with the concern utilizes the chronology. The chronology is continuously updated throughout the processing of the concern.

[2] Complete Attachment 8, Triage Form.

[3] Complete Attachment 24, Concern File Information Sheet.

[4] Perform a review of the OCP concern file to ensure, at a minimum, the file includes: Concern Summary Form(s); Concern Chronology; Concern File Information Sheet; Triage Form(s); and Confidentiality Statement, if applicable.

5.5 TRIAGE

Concern Program Analyst

[1] Submit the concern file to the OCP Manager for triage.

OCP Manager

[2] Conduct the triage meeting for incoming concerns with Concerns Program Analyst to discuss the concern and recommendations for addressing the concern.

NOTE: Concerns are prioritized primarily on the basis of safety significance, but other factors considered include quality, HIRD, work environment, unlawful or fraudulent activities, recurrence of issues, etc. The goal is to complete most concerns within 30 days. For complex issues the goal is to complete the concern, as soon as possible, and within 90 days. The initiation time starts on the day that the concern/issue is triaged.

[3] Review and confirm the category and priority of concerns.

[4] Determine if a subject matter expert, technical/programmatic, and/or SCWE review may be required.

[5] Determine what avenue of disposition is appropriate: **(Ref: DOE O 442.1A(4)(b)(1) & (5)(c)(7))**

- Investigated or otherwise evaluated through the OCP, in coordination with DOE or external offices when required;
- Referred to other offices or programs and tracked by the OCP until they are resolved;
- Transferred to other programs or processes (i.e, concerns deemed to be outside the scope of OCP);
- Addressed as a Non-Investigative Resolution; or
- Dismissed (non-sufficient information).

NOTE: For referred concerns, unless otherwise agreed to by the employee, an organization other than that of the employee's immediate supervisor (typically two levels up) conducts the investigation. Similarly, individuals or organizations outside the concerned employee's organization should not be selected to conduct the investigation where their involvement presents a conflict of interest. **(Ref: DOE 442.1A(4)(b)(4))**

[6] Assign the concern file to a CPA.

[7] Provides Administrative Assistant with the concern file.

Administrative Assistant

[1] Enter concern file information into the OCP concern database.

[2] Return the concern file to the CPA for processing.

5.6 TRANSFER

Concerns Program Analyst

[1] Verbally notify the CI of the impending transfer to another organization/agency and document contact in the Attachment 6, "Concern Chronology."

[2] Prepare either: Attachment 9, "Transfer OCP Concern to DOE" (memo) or Attachment 10, "Transfer OCP Concern to a Non-DOE Office" (letter).

NOTE: Concerns may be transferred to another DOE or contractor organization with jurisdiction over the issue. A concern is transferred/assigned to the line management in which the concern exists or to an independent line organization (when necessary to ensure a conflict of interest will not exist).

[3] Provide the concerns file to Administrative Assistant for transfer letter finalization.

Administrative Assistant

[1] Review the draft letter to ensure consistency with DOE correspondence requirements, including grammatical correctness.

[2] Print the letter on appropriate letterhead.

[3] Provide finalized letter to the CPA.

Concerns Program Analyst

[1] Review transfer letter to ensure accuracy.

[2] Submit the transfer letter with the OCP file to the OCP Manager.

OCP Manager

[1] Review and sign the transfer letter.

NOTE: If the letter requires revision, the OCP Manager discusses the issue with the CPA and/or provides the letter to the Administrative Assistant for revision. If the letter revision consists of other than grammatical changes, the Administrative Assistant will return the file to the CPA prior to the OCP Manager signing the letter.

[2] Return OCP file to Administrative Assistant.

Administrative Assistant

[1] Process the concern in accordance with DOE records requirements, which includes, but is not limited to: copying letter and attachment; filing official record in concern file; mailing letter to organization; and inputting data into the electronic OCP database.

[2] Return concerns file to the CPA.

5.7 REFERRAL

Concerns Program Analyst

[1] Verbally notify the CI of the impending transfer to another organization/agency and document contact in the concern chronology.

[2] Prepare either: Attachment 11, "Referral to DOE" (memo) or Attachment 12, "Referral to Non-DOE" (letter).

[3] Provide the concern file to Administrative Assistant for letter finalization.

Administrative Assistant

[1] Review the draft letter to ensure consistency with DOE correspondence requirements, including grammatical correctness.

[2] Print the letter on appropriate letterhead.

[3] Provide finalized letter to the CPA.

Concerns Program Analyst

[1] Review letter to ensure accuracy.

[2] Submit the letter with the OCP file to the OCP Manager.

OCP Manager

[1] Review and sign letter.

NOTE: If the letter requires revision, the OCP Manager discusses the issue with the CPA and/or provides the letter to the Administrative Assistant for revision. If the letter revision consists of other than grammatical changes, the Administrative Assistant will return the file to the CPA prior to the OCP Manager signing the letter.

[2] Return file to Administrative Assistant.

Administrative Assistant

[1] Process the concern in accordance with DOE records requirements, which includes, but is not limited to: copying letter and attachment(s); filing official letter in concern file; mailing letter to the organization; and inputting data into the electronic OCP database.

[2] Return concern file to the CPA.

Concerns Program Analyst

[1] Monitor the progress of the investigation to ensure the referred to organization responds within the designated timeframe.

NOTE: This may require the CPA to correspond or contact the referred to organization responsible for investigation to ensure progress is being made and the timeframe will be met. All such contacts will be documented on Attachment 6, "Concerns Chronology Form."

Administrative Assistant

[1] Receive response, affixes date-stamp and distributes to CPA.

Concerns Program Analyst

[1] Review response against initial concern.

[2] Prepare Attachment 22, "OCP Evaluation of Concern Referral Response."

[3] Submit evaluation and OCP file to the OCP Manager.

OCP Manager

[1] Review evaluation to ensure compliance with DOE requirements and concur by signature.

[2] Provide feedback to specific organizations, if necessary.

[3] Return file to the CPA.

Concerns Program Analyst

[1] Process concern file based upon evaluation concurrence.

NOTE: Actions could include, but are limited to: concern file closure, initiating Attachment 13, "Management Action Tracking Form," additional follow-up, etc.

[2] If concern file closure is initiated, refer to Section 5.11, "Concern File Closure."

5.8 NON-INVESTIGATIVE RESOLUTION (NIR):

Concerns Program Analyst

[1] Notify CI of actions to be taken.

[2] Initiate actions identified in the triage process.

[3] Prepare Attachment 14, "Non-Investigative Resolution Form."

[4] Submit NIR form to the OCP Manager with the OCP concern file.

OCP Manager

[1] Review NIR and approve by signature.

[2] Return file to CPA.

Concerns Program Analyst

[1] Initiate closure of concern file in accordance with Section 5.11, "Concern File Closure."

OR

[2] Prepare Attachment 13, "Management Action Tracking Form(s)," as necessary.

5.9 INVESTIGATION

Concerns Program Analyst

[1] Review the concern intake file and prepare Attachment 15, "OCP Investigation Plan."

NOTE: Investigation plan can include multiple concerns contained within a concern file.

[2] Submit investigation plan with OCP concern file to OCP Manager for concurrence.

OCP Manager

[3] Review the investigation plan with the OCP concern file and concur by signature.

NOTE: Initiate legal review if necessary.

[1] Return OCP concern file to CPA.

Concerns Program Analyst

[1] Periodically brief the CI on the status of the investigation, at minimum contact should be made every 30 days. This document should be documented in Attachment 6, "Concern Chronology."

NOTE: The briefing to the CI should only discuss the status of the investigation (i.e., in progress, completed and pending investigation report finalization). The CI is NOT to be briefed on the conclusions or details associated with the investigation at this time!

Notify the OCP Manager and the CI if, during the course of the investigation, the OCP Analyst determines that confidentiality is an impediment to completing the investigation. Any contacts with the CI are to be documented in Attachment 6, "Concern Chronology."

[2] Thoroughly investigate each concern as identified in the investigation plan.

[3] Document all interviews conducted during the OCP investigation. Documentation will vary from complex records to simple annotations in the concern chronology.

[4] Periodically brief the OCP Manager on the status/progression of the investigation and identify areas that require management assistance, such as but are not limited to: additional issues outside the scope of the investigation are identified or any potential reportable issues are identified. **(Ref: DOE 442.1A(b)(7))**

[5] Prepare Attachment 17, "OCP Investigation Report."

[6] Submit investigation report and OCP file to OCP Manager.

OCP Manager

[1] Review investigation report.

[2] Initiate legal review of report, if necessary.

[3] Approve report by signature.

[4] Return concern file to CPA.

Concerns Program Analyst

[1] Review concern file to determine if management actions are required and initiate Attachment 13, "Management Action Tracking Form";

OR

[2] Initiate OCP concern file closure in accordance with Section 5.11, "Concern File Closure."

5.10 TRACKING MANAGEMENT ACTIONS

Concerns Program Analyst

[1] Interface with responsible management to identify appropriate management actions.

[2] Prepare Attachment 13, "OCP Management Action Tracking Form(s)."

[3] Obtain signature(s) of responsible individuals as required on Attachment 13, "OCP Management Action Tracking Form(s).

[4] Submit management action form(s) to OCP Manager for approval.

OCP Manager

[1] Review management actions to ensure consistency with deficiencies identified.

[2] Sign management action form(s).

[3] Provide management action form(s) and concern file to the Administrative Assistant.

Administrative Assistant

[1] Update the electronic Management Action Tracking database.

[2] Return file to Concerns Program Analyst.

Concerns Program Analyst

[1] Monitor the progress/status of the management actions to ensure completion of identified actions within the timeframe identified.

NOTE: The OCP Manager must approve any extension of management actions associated with HIRD, Chilling Effect or SCWE related issues. For other types of concerns, if an extension is requested, the CPA will document in Attachment 13, "Management Action Tracking Form," the new due date and the reason the extension was granted. If, more than one extension is requested, notify the OCP Manager prior to approval.

OCP Manager

[2] Advise appropriate levels of management when actions are ineffective or not timely in resolving concerns or correcting identified deficiencies. **(Ref: DOE 442.1A(4)(c)(12))**

5.11 CONCERN FILE CLOSURE

Concerns Program Analyst

[1] Prepare Attachment 18, "Final Response Letter."

[2] Provide the concern file to Administrative Assistant for letter finalization.

Administrative Assistant

[1] Print the letter on appropriate letterhead.

[2] Review the draft letter to ensure consistency with DOE correspondence requirements, including grammatical correctness and prints the letter on appropriate letterhead.

[3] Provide finalized letter to the CPA.

Concerns Program Analyst

[1] Review letter to ensure accuracy.

[2] Submit the letter with the concern file to the OCP Manager.

OCP Manager

[1] Review and sign the letter to the CI.

NOTE: If the letter requires revision, the OCP Manager will discuss areas of concern with the CPA and/or provides the letter to the Administrative Assistant for revision. If the letter revision consists of other than grammatical changes, the Administrative Assistant will return the file to the CPA prior to the OCP Manager signing the letter.

[2] Return file to Administrative Assistant.

Administrative Assistant

[1] Process the concern in accordance with AP-17.1Q, Records Management, which includes, but is not limited to: copying letter and attachment; filing official record in concern file; mailing letter to the CI; and inputting data into the electronic OCP database.

[2] Return concern file to the CPA.

Concerns Program Analyst

[1] Perform final review of concern file to ensure all required documentation is included in file and initiate closure.

[2] Provide concern file to the Administrative Assistant.

Administrative Assistant

[1] Complete Attachment 24, "Case Information Sheet" and close file.

5.12 WITHDRAW OF CONCERN

It is preferred that the CI prepare a written request of withdraw for inclusion in the OCP file. The CI may choose to withdraw a concern at any time during the process and the OCP Manager will consider the request. Final determination remains with the OCP Manager and the rationale for the decision must be documented in Attachment 6, "Concern Chronology" or in a note to the file.

5.13 APPEAL PROCESS

Concerned Individual

[1] Contact the OCP Manager to discuss reasons for appeal.

OCP Manager

[1] Consider any comments offered by the CI and inform the CI of the results of the consideration.

[2] File the results of the consideration in the concern file.

[3] Notify the CI of their right to contact DOE management having jurisdiction over the OCP, the NRC or the DOE HQ Office of Employee Concerns. **(Ref: AP-32.1/4.3, 5.5, & DOE O 442.1A/4.c.2)**

OCRWM Senior Management [1] Consider the appeal by the CI and communicate the results of the consideration to the CI and OCP Manager.

OCP Manager [1] Documents the results of the consideration in the OCP concern file.

5.14 EXIT INTERVIEWS

All exiting OCRWM employees and contractors directly supporting OCRWM have the opportunity to either participate in an exit interview with an OCP staff member or are provided a letter requesting they report any concerns they may have upon departure from the project.

THIS SECTION IS UNDER DEVELOPMENT

5.15 SELF-ASSESSMENTS

OCP Manager [1] Perform annual self-assessment consistent with LP-PM-001, "OCRWM Self-Assessment Program." **(Ref: DOE 442.1A (4) (f), (5) (c) (10) and OI Item # 7)**

5.16 INTERFACES

The OCP develops interface with the following organizations for advice and assistance in addressing matters within their areas of expertise and jurisdiction: **(Ref: DOE O442.1A (4) (a) (1) & OA Item #1))**

- DOE Office of Inspector General;
- Labor Relations organization(s);
- Environmental Safety and Health organization(s);
- Employee Relations, EEO and Human Resource organizations;
- Employee Assistance Program(s);
- Security organization(s);
- Contractor employee concern program organization(s);
- DOE HQ Office of Employee Concerns;

- Other DOE and DOE contractor ECP's;
- DOE Employee Concerns field managers and/or coordinators;
- FOIA/Privacy Act Officer; and
- NRC representatives or other external regulatory bodies that oversee concern program organizations.

5.17 PERIODIC REPORTS

Administrative Assistant

[1] Prepare reports as requested by the OCP Manager. These include, but are not limited to: **(Ref: DOE O442.1A (4)(c)(9)&(4)(d)(2))**

- DOE HQ Quarterly Report;
- DOE HQ Annual Report; and
- Special Reports.

OCP Manager

[1] Distribute periodic reports and review them for lessons learned and possible adverse trends. **(Ref: DOE O 442.1A (4) (c) (9))**

[2] Document and communicate lessons learned, possible adverse trends to OCRWM Director, ORD Deputy Director and other senior managers. **(Ref: DOE O 442.1A (4) (c) (9))**

5.18 TRAINING AND QUALIFICATONS

The OCP Manager position qualifications are documented in OPM position qualification requirements and in the Position Description available from the OCRWM Human Resources organization.

Qualifications for OCP support personnel are identified in Contract #DE-AF28-04RW12241. **(Ref: DOE 442.1A (4)(e) & OA Item # 6)**.

5.19 ADVERTISING, PROMOTION AND PROGRAM VISIBILITY

This section is under development as part of the SCWE Action Plan commitment to develop a Communications Strategy and Plan.

6.0 RECORDS

The records listed in Subsections 6.2 shall be retained by OCP. This retention is to assure the identity of each CI is protected consistent with the employee's request for confidentiality and the provisions of the DOE System of Records DOE-3, "Employee Concerns Program Records," and Exemption 6 of the Freedom of Information Act (FOIA). OCP records shall be dispositioned in accordance with AP-17.1Q, "Records Management," OCP file plan instructions, and approved DOE Records Disposition Schedules.

Access to OCP files is limited to those having a "need to know". Access to the file room is controlled by OCP personnel. OCP Concern files are maintained in lockable, fireproof file cabinets. Names of individuals granted access are listed on placards posted on each file cabinet and updated as necessary.

Requests for information from concern files must be referred to the ORD FOIA/Privacy Act Officer to prepare a response.

Access to records is approved by the OCP Manager. Any individual granted access to a specific concern file must sign an "Acknowledgement of Agreement of Confidentiality for Participation in OCRWM Concerns Program Activities." The OCP Manager may authorize individual's access on a case-by-case basis.

The content of OCP files may vary from year to year (i.e, "Calendar Year") as a result in changes in OCP management expectations.

6.1 QA RECORDS

None.

6.2 NON-QA LONG-TERM RECORDS

Official Concerns Program Files.

Exit Forms and Exit Documentation.

Records Documenting Concerns That Do Not Develop Into Official Cases.

6.3 NON-QA SHORT-TERM RECORDS (THREE YEARS OR LESS RETENTION)

None.

7.0 ATTACHMENTS

Forms attached to this DPI are controlled and distributed as full-size pages separate from this DPI and may be copied for use as necessary. The change history for this DPI is included as Attachment 24, Change History. Attachments to this DPI may be revised as necessary without

requiring a complete revision to the OCP DPI itself (updated electronic forms are stored on the OCP secure file server).

1 OCP Process Flowchart
2 Acronyms and Abbreviations
3 Definitions
4 Intake Interview Guideline
5 Confidentiality Statement
6 Chronology
7 Concern Summary Form
8 Triage Form
9 Transfer to DOE (memo)
10 Transfer to Non-DOE (letter)
11 Referral to DOE (memo)
12 Referral to Non-DOE (letter)
13 Management /Corrective Action Tracking Form
14 Non-Investigative Resolution (NIR)
15 Investigation Plan
16 Chilling Effect Guide
17 Investigation Report
18 Final Response Letter
19 Concern Initiation Form
20 Acknowledgement of Receipt OCRWM Concerns Program Information
21 Exit Letter
22 OCP Evaluation of Concern Referral Response
23 Acknowledgement of Agreement of Confidentiality for Participation in OCRWM Concerns Program Activities
24 Concern File Information Sheet
25 Change History

OCP Process Flow-Chart

Acronyms and Abbreviations

CAQ	Condition Adverse to Quality
CFR	Code of Federal Regulation
CI	Concerned Individual
CPA	Concerns Program Analyst
DOE	U.S. Department of Energy
DPI	Detailed Process Instruction
ESCN	Employee Status Change Notification
FOIA	Freedom of Information Act
HIRD	Harassment, Intimidation, Retaliation or Discrimination
MSPB	Merit System Protection Board
NIR	Non-Investigative Resolution
NNSA	National Nuclear Security Administration
OCP	Office of Civilian Radioactive Waste Management Concerns Program
OCRWM	Office of Civilian Radioactive Waste Management
ORD	Office of Repository Development
OSC	Office of Special Counsel
OSPD	Office of Strategy and Program Development
SCWE	Safety Conscious Work Environment
USPS	United States Postal Service

Definitions

Adverse Action–An employment action that materially alters the terms, conditions or privileges of a person's employment. **(Ref: SCWE Charter dated 1/26/05)**

Anonymous–The identity of the concern individual(s) is unknown.

Chilling Effect–A work environment where the willingness of employees to report safety or quality concerns is inhibited. Some actions intentionally or unintentionally taken by management, managers, supervisors, contractors or employees may be viewed as inhibiting the willingness of employees to report safety or quality concerns. **(Ref: SCWE Charter dated 1/26/05)**

Concern–A good faith expression by an employee. Concerns can address issues such as health, safety, quality, environmental, management practices, or reprisal for raising a concern. **(Ref: DOE O 442.1A (7) (d) & AP 32.4 (Attachment 2) Note: fraud and waste was removed from original DOE Order and AP definitions))**

> The OCP is not intended to replace existing processes/systems that address certain concerns (i.e. allegations of waste, fraud, and abuse; security; union grievance issues, equal employment opportunity (EEO) issues or personnel policy issues), as there are established systems to address these matters.

Concern Category Code–The method used by OCP to identify the subject matter of the concern. The codes used by OCP are: Security Safety, Health, Environment, Waste/Fraud/Abuse, Human Resources, EEO, Quality, Management /Mismanagement, Workplace Violence, Harassment /Intimidation/Retaliation/Discrimination/Chilling Effect (HIRD) and other. **(Ref: DOE O 442.1A (1))**

Concerned Individual (CI)–A person expressing a concern through the OCP.

Concerns Program Analyst - Members of the OCP staff assigned by the OCP Manager to perform investigation and/or concerns processing responsibilities.

Confidential Concern - A concern submitted by an Employee who wishes to have their identity protected from all persons except the OCP staff or those with a need to know. (Ref: DOE G 442.1A (2))

Conflict of Interest - A situation in which the person responsible for investigating an employee concern could be associated either directly or indirectly with that concern or an investigative task is assigned to a person who might have submitted the concern. **(Ref: DOE O 442.1A (7) (b))**

Contact - An informal discussion initiated by an individual with the OCP where the individual is informed of available avenues of redress and chooses not to utilize the OCP process or an *i*nteraction between the OCP and a CI that results in the initiation of a concern.

Definitions (Continued)

Discrimination - An adverse employment action (e.g., discharge, discipline, poor performance evaluation, failure to provide promotions or raises, exclusion from job opportunities, etc.) initiated against an individual for reasons other than job performance. Treating one person or class of persons differently from another when the reason for that different treatment is because of gender, race, color, religion, national origin, age, disability, or participation in protected activities. **(Ref: NEI (C-17))**

Duty to Act - OCP personnel take immediate action and report any concern that involves an imminent danger /condition or a serious condition to the OCP Manager.

Employee - Any person working for DOE, a DOE contractor or subcontractor on a DOE project. **(Ref: DOE O442.1A (7) (c))**

Environmental Concern - An alleged condition where practices, emissions, or the release of substances into the environment have been uncontrolled.

Evaluation - An inquiry conducted by or a review of documentation by OCP for the purpose of addressing a concern. The details of evaluations will vary depending on the nature of concerns. Evaluations range from discussions with personnel to conducting investigations. **(Ref: _____)**

Harassment - Actions (words, gestures, graphics, pictures, offensive language, differential treatment, taunting, etc.) that offend, discomfort, or demean an employee or create a hostile work environment or compel an employee not to perform duties and responsibilities or to refrain from engaging in protected Activities. **(Ref: NEI (C-18)**

Hostile Work Environment - An intimidating or offensive work environment directed at members(s) of a protected class, including individuals who have opposed a practice or participated in an investigation, proceeding, or hearing, or engaged in such other protected activities as are covered by law or regulation. **(Ref: NEI 97 - 05 (S-1))**

Imminent Danger Condition - Any condition or practice in any workplace that creates a danger that could reasonably be expected to cause death or serious physical harm immediately or before the danger could be eliminated through the normal procedural mechanism. ES&H requires that such concerns be investigated within 24 hours. **(Ref: DOE O 442.1A (7) (e))**

Indeterminate - Facts neither supports or negates the alleged condition as stated.

Intake - Interaction with a Concerned Individual (CI) to discuss all information about a concern, document the concern and determine the appropriate resolution method to address it.

Intimidation - Any action(s) that has the effect, or perceived effect, by the CI, taken by coworkers or supervisor against or toward an employee to cause that employee to cease engaging in protected activities; to be fearful of engaging in protected activities; or to otherwise be afraid for his or her safety, reputation, or job security as a result of having identified concerns about any aspect of DOE facilities or operations. **(Ref: DOE O 442.1A (7) (f) & NEI 97 - 05 (S-2))**

Definitions (Continued)

Investigation - An inquiry conducted by or on behalf of OCP for the purpose of evaluating and resolving a concern, usually involving interviews , inspection of relevant documents, sites, or equipment, and an evaluation of practices follows. **(Ref: DOE G 442.1A (7g)**

Issue - A specific subject matter held by or perceived by an individual. A concern file may be broken down into one or more issues.

Management Concern - An alleged condition related to management behavior, policy, practice, budget allocation and/or use of resources.

Need to Know - A situation where an individual requires some knowledge of a concern or the identity of the CI to enable the individual to contribute to the concern evaluation or to perform other official duties. This is determined by the OCP Manager with the concurrence of the CI.

Non-Investigative Resolution - Method used to address and document concerns promptly in instances where minimal effort is necessary to resolve a concern and effectively address it. NIRs are normally used when action can be completed in less than a week. NIRs are not appropriate for investigations associated with allegations of HIRD or Chilling Effect.

Not Substantiated - Facts do not support the alleged condition as stated.

OCRWM Concerns Program Hotline - A 24-hour telephone system that allows OCRWM personnel to express a concern.

Other - Than - Serious - Condition - Hazards, violations, or conditions that may not result in death or serious physical harm, property loss, and /or environmental impact but may have a direct and immediate relationship to worker safety and health or the environment. ES&H requires that such concerns be investigated within 20 working days. **(Ref: DOE G 442.1A (8))**

Prima Facie Case of Retaliation – A Prima Facie Case of Retaliation exist if it can be demonstrated that the employee was involved in a protected activity, an adverse action was taken, management had knowledge of an employee's involvement in a protected activity, and the employee's involvement in a protected activity was a contributing factor to management's decision to proceed with an adverse action exists. **(Ref: SCWE Charter dated 6/26/05)**

Priority - Precedence of action to be taken on a concern.

Protected Activities - Activities such as raising concerns or otherwise making disclosures protected under law, regulations, or legal precedent of information related to DOE operations, which the individual reasonably and in good faith believes is evidence of unsafe, unlawful, fraudulent, or wasteful practices. Examples include , but are not limited to , activities in which an employee notifies their employer of an alleged violation of U.S. Nuclear Regulatory Commission Program requirements; Refuses to engage in any practice made unlawful by the Energy Reorganization Act of 1974 or the Atomic Energy Act of 1954, if the employee has identified the alleged violation to their employer; testifies before Congress or at any Federal or State proceeding regarding any provision o f the Energy Reorganization Act or the

Definitions (Continued)

Atomic Energy Act of 1954;Provides the NRC with information about possible violations of the NRC requirements ;Requests NRC action; testifies in any NRC or Department of Labor proceeding; Commences or participates in a proceeding under Section 211 of the Energy Reorganization Act; or Notifies their employer , supervisor , OCRWM Concerns Program or BSC ECP Coordinator, or the NRC of an alleged nuclear safety or quality Concern. **(Ref: SCWE Charter dated 1/26/05)**

Quality Concern - An alleged condition that may indicate activities have not met quality requirements.

Referral of a Concern - Transmittal of an employee concern to another organization or process for investigation or resolution, with the results of the investigation or resolution attempts being reported to the ECP Manager within a specified time period. **(Ref: DOE O 442.1A (7) (h))**

Reportable Concern - A condition that requires notification to the NRC.

Reprisal - Any action taken against an employee in response to, or in revenge for, the employee having raised, in good faith, reasonable concerns about any aspect of DOE related operations. Reprisals against contractor employees may lead to the imposition of penalties under the Price Anderson Amendments Act of 1988 (Pub. L. 100 - 49, August 20, 1988), implemented by DOE under 10 CFR Part 820 (Part 820). Pursuant to Part 820, to the extent a reprisal by a DOE contractor results from an employee's involvement in matters of nuclear safety in connection with a DOE nuclear activity, the reprisal could constitute a violation of a DOE Nuclear Safety Requirement. **(Ref: DOE O 442.1A (7) (g))**

Resolution of Concern – Action(s) taken and decision made in response to an employee concern by verifying the concern, establishing plans to correct identified deficiencies, correcting the deficiencies, or determining that the concern is not substantiated and no corrective action is required. **(Ref: DOE 442.1A (7) (j))**

Retaliation - An action that has the effect of punishing a person for engaging in legally protected activities. **(Ref: NEI (C - 18))**

Safety - An alleged condition related to the safety or health aspects of an activity.

Safety Conscious Work Environment (SCWE) - A work environment in which employees feel free and encouraged to raise concerns without fear of retaliation and where concerns are promptly reviewed, prioritized based on potential safety significance, and appropriately resolved with timely feedback to the employees. **(Ref: POL - YMP - 2004 - 004)**

Serious Condition - A hazard, violation, or condition that causes a substantial probability that death or serious physical harm, property loss, and/or environmental impact could result. ES&H requires that such concerns be investigated within 3 working days. **(Ref: DOE G 442.1A (8))**

Substantiated - Facts support the alleged condition.

Definitions (Continued)

Substantiated/Previously Addressed - Previous activities support the alleged condition and it has been addressed or will be addressed through a traceable process.

Transfer of a Concern - Transmittal of a concern by the OCP to an office with subject - matter responsibility or expertise pursuant to which that office will address the concern with the concerned employee. No response to OCP is required. **(Ref: DOE O 442.1A)**

Triage – An OCP internal process used to discuss concerns, confirm issues, and determine the planned method to evaluate the concern. Concern classification and priority are confirmed during the triage process.

Withdrawal - An Action taken by a CI to discontinue the OCP processing of a concern further.

Intake Interview Guideline

1. Please describe your concern?
2. During what period or periods did the events occur?
3. Does the situation continue?
4. Is your concern based on first hand knowledge?
5. What, if any, prior attempts to report or resolve the concern have been made by you or by others? If line management was not given the opportunity to assist, why not?
6. Who (Name, Position, Organization) are the people involved in the situation related to your concern?
7. Are there others who share your concern? If so, who are they?
8. (If the concerned individual describes an issue or problem in general terms) Do you have specific evidence that demonstrates that a problem exists or can you provide me with examples that support the issue you are describing?
9. Can you identify and/or provide any documents, such as procedures, e-mail, memos, etc. that are related to your concern?
10. In your opinion, does the concern create a severe or urgent threat to the health and safety of yourself, other employees, contractor personnel or the public
11. Are there any persons or organizations (including line management) that you prefer we not discuss your concern with during the course of our investigation? Why?
12. What action(s) do you believe might help in the resolution of your concern?
13. While working at OCRWM have you felt free to report problems or raise issues?
14. Have you raised issues or reported problems in the past? If so, how?
15. Were you satisfied with the manner in which you previously reported issues or problems were processed and resolved?

Confidentiality Statement

Chronology

QA: N/A

CONCERN CHRONOLOGY

OCP Number O - YY - ###

DATE	POC	CONCERN INVESTIGATION ACTIVITY

Concern Summary Form

U.S. DEPARTMENT OF ENERGY
OCRWM Concerns Program (OCP)
Concern Summary Form

OCP Case Number:	O - yy - ###	Concern/Issue Number:	.##

Concern/Issue Statement:

Background Information:

Concerned Individual Signature **Date**

When completed, this form may contain privacy act information

Triage From

Transfer to DOE (Memo)

QA: N/A

Date

MEMORANDUM FOR: [First Name] [MI] [Last Name] (RW - #W)

FROM: Julie A. Goeckner, Manager
OCRWM Concerns Program

SUBJECT: Transfer of OCRWM Concern O [yy - ###]

The Office of Civilian Radioactive Waste Management (OCRWM) Concerns Program (OCP) received the following concern on [date received] and is transferring this concern to you for appropriate disposition:

OCP considers this file closed with the transfer of this concern. No response to OCP is required. If you have any questions or require additional clarification, please contact Julie A. Goeckner, Manager OCRWM Concerns Program, on (702) 295 - 2694.

Enclosure(s):
1.

Transfer to Non DOE Entity (Letter)

QA: N/A

date

[First Name] [MI] [Last Name], [Title]
[Department]
[Company]
[Address], M/S [mail stop #]
[city], [ST] [zip]

TRANSFER OF OCRWM CONCERNS NUMBER O [YY - ###]

Dear :

The Office of Civilian Radioactive Waste Management (OCRWM) Concerns Program (OCP) received the following concern on [date received] and is transferring this concern to you for appropriate disposition:

[Concern]

OCP considers this file closed with the transfer of this concern. No response to OCRWM OCP is required. If you have any questions or require additional clarification, please contact me on (702) 295 - 2694.

Sincerely,

Julie A. Goeckner, Manager
OCRWM Concerns Program

Enclosure(s):
1.

Referral to DOE (Memo)

Date

MEMORANDUM FOR: [First] [MI] [Last] (RW - #W)

FROM: Julie A. Goeckner, Manager
OCRWM Concerns Program

SUBJECT: Referral of OCRWM Concerns Program Concern File #O - YY - ###.##

The OCRWM Concerns Program (OCP) is referring this concern to you for your review and response. The concern was received on [date] and is summarized as follows:

O - YY - ###.## - [Concern Summary Statement]

Your response is requested by [date]. In your response, please state the results of your investigation, whether or not the issue is substantiated, the basis and/or facts supporting your conclusion(s) and any proposed management actions.

Enclosed is a copy of the Concern Summary form that along with the concern statement also provides some background information. Also attached are some investigation tips intended to aid in your investigation of this issue.

Your cooperation is greatly appreciated in this matter. If you have any questions or require further clarification, please contact me on (702) 295 - 2694.

Enclosures:

1. Concern Summary Form O - YY - ###.##
2. Investigation Tips

Referral to Non - DOE (Letter)

QA: N/A

date

[First Name] [MI] [Last Name], [Title]
[Department]
[Company]
[Address], M/S [mail stop #]
[city], [ST] [zip]

REFERRAL OF OCRWM CONCERNS NUMBER O [YY - ###]

Dear :

The OCRWM Concerns Program (OCP) is referring this concern to you for your review and response. The concern was received on [date] and is summarized as follows:

O - YY - ###.## - [Concern Summary Statement]

Your response is requested by [date]. In your response, please state the results of your investigation, whether or not the issue is substantiated, the basis and/or facts supporting your conclusion(s) and any proposed management actions.

Enclosed is a copy of the Concern Summary form that along with the concern statement also provides some background information. Also attached are some investigation tips intended to aid in your investigation of this issue.

Your cooperation is greatly appreciated in this matter. If you have any questions or require further clarification, please contact me on (702) 295 - 2694.

Sincerely,

Julie A. Goeckner, Manager
OCRWM Concerns Program

Enclosures:
1. Concern Summary Form O - YY - ###.##
2. Investigation Tips

Management Action Tracking Form

U.S. DEPARTMENT OF ENERGY
OCRWM Concerns Program (OCP)
Management Action Tracking Form

OCP Case Number:	O - 05 -	**Concern/Issue Number**	.
		Management Action Issue Number:	

Responsible OCP POC:		Date:	

Description of Condition:

Proposed Management Action:

Responsible Manager:			
Date Responsible Manager Briefed:			
Scheduled Completion Date:			
Responsible Manager Concurrence:		Date:	
Responsible Individual:			
Responsible Individual Concurrence:		Date:	
OCP Manager Concurrence:		Date:	

Revised Completion Date and Justification, If Needed:

Comments/Notes:

Management Action Verified:		Date Completed:		Documentation Attached:	
	Initials			☐ Yes	☐ No

OCP Manager Closure Concurrence:		Date:	

Non - Investigative Resolution (NIR)

U.S. DEPARTMENT OF ENERGY
OCRWM Concerns Program (OCP)
Non - Investigative Resolution Form

OCP Case Number:	O - 05 -	**Concern/Issue Number:**	.

CPA Conducting the NIR:		**Date of completion of the NIR:**	

Type of non - investigative resolution:

Motivated management to address a problem (MM) ☐
Facilitated a meeting (FM) ☐
Educate, coach or mentor management (EC) ☐
Provided advice (PA) ☐
Spoke for the CI (SP) ☐
Other (OT) ☐

Method of resolving the CI's Issue:

method

CPA Signature _____ Date _____

OCRWM Concerns Program Manager _____ Date _____

When completed, this form may contain privacy act information

Investigation Plan

U.S. DEPARTMENT OF ENERGY
OCRWM Concerns Program (OCP)
Investigation Plan

QA: N/A

OCP Case Number:	O - yy - ###	**Concern/Issue Number:**	.##

I. Concern Statement:

II. Questions to Ask/Answer (Examples):

A. Who? (Who did it? Who Knows?)
B. What? (What have you done about it?)
C. When? (When did it happen?)
D. Where? (Where did it happen?)
E. Why? (Likely Cause?)

III. Records or other Documentation to Review:

IV. Individuals to Interview:

V. Deliverables and Due Dates (Examples):

CPA Signature _____ Date _____

OCRWM Concerns Program Manager _____ Date _____

When completed, this form may contain privacy act information

Chilling Effect Guide

QA: N/A

U. S. DEPARTMENT OF ENERGY
Office of Civilian Radioactive Waste Management
Guideline for Evaluating a Chilling Effect

OCP Case Number:	O - yy - ###	Concern/Issue Number:	.##

1. Are there any events or issues that have impacted your willingness to voice your opinion?
   YES [ ] NO [ ]

   If yes, please describe or give examples.

2. Have you raised concerns or issues with your management or supervision?
   YES [ ] NO [ ]

   If no:

   2a. Is it because you have had no concerns, or is it because you had concerns, but were reluctant to raise them?
   YES [ ] NO [ ]

   2b. If reluctant, why?

   2c. What do you think needs to happen before you would be willing to raise concerns?

   If yes:

   2d. How did management treat you after raising the issue?

   2e. How did your peers treat you after raising the issue?

   2f. Did you receive an adequate answer to your concern?
   YES [ ] NO [ ]

   2g. Was the response timely?
   YES [ ] NO [ ]

Chilling Effect Guide (Continued)

2h. Was there an investigation regarding your concern? (Did it receive adequate evaluation and consideration?)
YES [ ] NO [ ]

2i. Did this experience affect your willingness to raise issues in the future? Why, or why not?

3. Are you aware of others in your work group who has raised concerns with immediate supervision or senior management?
YES [ ] NO [ ]

If yes:

3a. How were their concerns handled?

3b. Did they suffer any form of retaliation from management?
YES [ ] NO [ ]

3c. How did their peers treat them?

3d. Did these events affect your willingness to raise concerns?
YES [ ] NO [ ]

If yes, please explain.

If no:

3e. Are others reluctant to raise concerns?
YES [ ] NO [ ]

If yes, why do you think they are reluctant?

3f. What's the basis for your opinion?

Chilling Effect Guide (Continued)

4. How would you assess or rate your immediate supervisor's receptivity to the raising of concerns?
   High [ ] Moderate [ ] Low [ ]

   What's the basis for your opinion?

5. How would you assess or rate senior management's receptivity to the raising of concerns?
   High [ ] Moderate [ ] Low [ ]

   What's the basis for your opinion?

6. Are you aware of resources, other than your management chain - or - command, which are available to listen to your concerns (i.e. Concerns Program, Ombudsman, Human Resources, NRC or other groups)?
   YES [ ] NO [ ]

   6a. Do you have any reluctance to use these?
   YES [ ] NO [ ]

   If yes, please explain.

   6b. If so, which ones? Why?

7. Do you have any additional information you would like to offer?

Name (Optional)	Company/Department	Date
CPA Signature		Date

When completed, this form may contain privacy act information

Investigation Report

QA: N/A

DEPARTMENT OF ENERGY
Office of Civilian Radioactive Waste Management
Concerns Program

INVESTIGATION REPORT NO. O - yy - ###.##

[CPA]
Concerns Program Analyst
OCRWM Concerns Program

Date

Julie A. Goeckner, Manager
OCRWM Concerns Program

Date

Investigation Report (Continued)

OCP INVESTIGATION REPORT

I. Concern Statement:

II. Investigation Details:

III. Conclusions:

Concern O - yy - ###.##:

1. Substantiated
2. Substantiated, but already addressed
3. Not Substantiated
4. Indeterminate

IV. References:

1. Personnel Contacted

2. Documents Reviewed

Final Response Letter

QA: N/A

Name
Address

OCRWM CONCERNS PROGRAM NUMBER O - YY - ###

Dear :

Thank you for bringing your concern to OCRWM Concerns Program (OCP). Below is a summary of your concern and the information OCP was able to obtain:

[Concern#]: Concern statement

Response:

Again, I appreciate you bringing your concern to this office. OCP is initiating closure of this concern file based upon the above information. If you disagree with this action, or believe that there is additional information that was not considered in this investigation, please contact me at (702) 295-2566.

Sincerely,

Julie A. Goeckner, Manager
OCRWM Concerns Program

Concern Initiation Form

Acknowledgement of Receipt

Exit Letter

QA: N/A

date

Name
Address
City, St Zip

EXIT INTERVIEW

Dear [name]:

As part of the exit interview process, it is the policy of the U. S. Department of Energy (DOE), Office of Civilian Radioactive Waste Management (OCRWM) to solicit feedback from each employee and contractor employee who performed work on any of the projects and/or facilities on site. As such, the OCRWM Office of Concerns Programs (OCP) requests your honest feedback.

As listed below, OCP offers you a number of alternatives to provide information and/or discuss any issues you have with regard to your work under the direction of the OCRWM.

Face-to-Face Meeting - A Concerns Program Analyst (CPA) is available to meet with you during our office hours. After hour office appointments are available if scheduled in advance. To schedule a meeting, telephone this office directly at the number below.

Telephone - A CPA is available by telephone at the number listed below.

Mail - Complete the attached Concern Initiation Form and mail it to this office in the postage - paid envelope provided.

Fax - Complete the attached Concern Initiation Form and fax it to this office at (702) 295-2755.

E - mail - Summarize your concern using the Concern Initiation Form as an outline and e - mail it to Julie_Goeckner@ymp.gov.

If there are any concerns, issues or suggestions you wish to document, you are encouraged to provide detailed information so that appropriate measures can be taken to mitigate the issues. Please indicate whether this office can contact you to request clarification, if needed. Any information provided will be handled confidentially, to the extent allowed by law.

Exit Letter (Continued)

Name - # - date

Regardless of whether you choose to document a concern or issue regarding your work experience at this site, you are requested to confirm your receipt of this letter by completing the "Acknowledgement of Receipt" form. **Please return this completed form, in one of the pre-paid postage envelopes, within 10 days of receipt of this letter.**

If you have any questions, please feel free to contact me at 1-800-874-5335 or (702) 295-2566. Or, come to the OCRWM OCP office located at 1160 N. Town Center Drive, Suite 110, during normal business hours (Monday through Friday, 7:00 am to 4:30 pm). Your response and efforts associated with this request are appreciated.

Sincerely,

Julie A. Goeckner, Manager
OCRWM Concerns Program

Enclosures:
1. Concern Initiation Form
2. Acknowledgement of Receipt
3. (2) Postage - paid envelope

OCP Evaluation of Concern Referral Response

U.S. DEPARTMENT OF ENERGY
OCRWM Concerns Program (OCP)
OCP Evaluation of Concern Referral Response

OCP Case Number:	O - yy - ###	Concern/Issue Number:	.##

Concern Statement:

Time Line:

Referral Response Conclusion:

Review Response Summary:

OCP Analysis of Response:

OCP Response Conclusion:

- ☐ Accept Response
- ☐ Return for Additional Information
- ☐ OCP to Gather Additional Information
- ☐ Other (Explain)

Recommendation:

OCP Analyst Signature _____ Date _____

Julie A. Goeckner, OCP Manager _____ Date _____

When completed, this form may contain privacy act information

Acknowledgement of Agreement of Confidentiality for Participation in OCRWM Concerns Program Activities

TO: **OCRWM Concerns Program**

FROM: _____

SUBJECT: ACKNOWLEDGMENT OF AGREEMENT OF CONFIDENTIALITY FOR PARTICIPATION IN OCRWM CONCERNS PROGRAM ACTIVITIES

I, _____, acknowledge and fully understand that all of my activities associated with the OCRWM Concerns Program (OCP) are to be handled in a *CONFIDENTIAL* manner. In this respect, I agree that I will not disclose any information relative to the identity of the individuals who contact the OCP with specific issues to anyone outside the immediate OCP staff without the OCRWM Concerns Program Manager's permission.

In addition, information related to either the details of a specific concern or to the status information on the progress of a specific investigation shall not be divulged to any individual outside the immediate Concerns Program staff unless I have received authorization from the OCRWM Concerns Program Manager.

I understand that any violation of this agreement will be referred to management within my respective organization for appropriate action.

_____ _____

Signature Date

Change History

Revision Number	Interim Change No.	Effective Date	DESCRIPTION OF CHANGE
0	0	07/08/2005	Initial issuance to establish the responsibilities, processes and actions taken by the OCRWM Concerns Program (OCP) to process and address employee Federal or contractor concerns in accordance with *AP - 32.1, Office of Civilian Radioactive Waste Management Concerns Program.* The DPI provides information and guidance to the OCP staff on training requirements, self - assessments, generating periodic reports, management interface, and OCP program awareness expectations.