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MEMORANDUM FOR: Paul Hildenbrand, Project Manager
Basalt Waste Isolation Project, WMRP
Division of Waste Management

FROM: Michael F. Weber, WMGT
Division of Waste Management

SUBJECT: DOCUMENT REVIEW OF HEADCO USER'S MANUAL, RHO-BW-ST-71 P

Enclosed please find a copy of my review of the document entitled "HEADCO: A Program for Converting Observed Water Levels and Pressure Measurements to Formation Pressure and Standard Hydraulic Head" [RHO-BW-ST-71 P] by F. Spane and R. Mercer. The HEADCO program is an important analytical tool that supports DOE's characterization of hydraulic gradients at the Hanford Site. Notwithstanding several deficiencies and limitations of the document, the HEADCO program constitutes a reasonable approach for converting field data to standard pressures and heads required for site characterization. Neil Coleman assisted me by reviewing the section on gravitational corrections to water levels and pressures. The enclosed review documentation has been reviewed by Mr. Coleman and Williams and Associates (Gerry Winter, Dale Ralston, and Roy Williams). I have also enclosed for your information reviews performed by Williams and Associates and Nuclear Waste Consultants (Terra Therma).

Based on our review, we have identified several deficiencies and limitations of the HEADCO document. We recommend that you transmit our review of the document to DOE-RL for consideration of our comments. Depending on DOE's response to these comments, we may need to review the documentation and use of the HEADCO program in greater detail in the future. Please contact me if you have any questions about this review.

/S/
Michael F. Weber
Geotechnical Branch
Division of Waste Management

Enclosures:
As Stated

WM Record File 101

WM Project 10
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WMGT DOCUMENT REVIEW SHEET

FILE #: 3101

DOCUMENT #: RHO-BW-ST-71 P

TITLE: HEADCO: A Program for Converting Observed Water Levels and Pressure Measurements to Formation Pressure and Standard Hydraulic Head (1985), by Spane, F. A., and Mercer, R. B.

REVIEWERS: Michael Weber and Neil Coleman

DATE REVIEW COMPLETED: February 28, 1986

REVIEW ABSTRACT:

This document describes the theoretical basis and provides a user's guide for the HEADCO computer program. BWIP developed HEADCO to aid in site characterization activities at the Hanford Site by converting water levels and pressures to standardized formation pressures and hydraulic heads. The program corrects water levels and pressures measured in the field for complications caused by variations of groundwater density and external stresses such as barometric and tidal changes. BWIP plans to use HEADCO to interpret field data collected presently and in the future. HEADCO may also aid investigators at other sites being considered as potential repositories for HLW.

Based on reviews by NRC staff and contractors (Williams and Associates, and Nuclear Waste Consultants), the HEADCO program appears to be a reasonable approach for converting field measurements of water levels and pressures to formation pressures and hydraulic heads. This conversion is necessary to assess the groundwater flow system at the Hanford Site. The review, however, identified several deficiencies of the report, including (1) insufficient discussion of the use of output from the program, (2) lack of references for assessments that support the document, and (3) insufficient validation of the program to ensure accurate conversion of field data to standardized values.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

HEADCO allows investigators to convert field measurements to standardized values by accounting for variables that complicate interpretation of the measurements. These variables are routinely ignored in groundwater investigations at shallower depths. They may, however, be important in the characterization of groundwater flow rates and directions at sites where ambient gradients are relatively low (i.e., less than 1E-3 m/m) or where

factors that affect hydraulic head vary considerably (e.g., systems with large salinity variations). Low hydraulic gradients and the high geothermal gradient at Hanford indicate that the complicating variables must be considered in characterizing the groundwater flow system. Thus, DOE must demonstrate that the application of the HEADCO program accurately converts field data to standardized formation pressures and hydraulic heads. This review assesses the HEADCO program and its potential applications in support of site characterization.

PROBLEMS, DEFICIENCIES, OR LIMITATIONS:

Overall, the HEADCO program constitutes a reasonable approach for converting field measurements of water levels and downhole pressures to standardized formation pressures and hydraulic heads. The document, however, suffers from several deficiencies, including: (1) insufficient discussion of the use of output from the HEADCO program, (2) lack of referenced assessments that support assumptions invoked in developing the program or that aid in program application, and (3) insufficient validation to assure accurate conversion of field data to hydraulic heads. The program is also limited because it cannot consider the effects of salinity variations of fluid within a borehole.

Output Use

The HEADCO document describes the theoretical basis and use of the program in sufficient detail. It does not, however, sufficiently discuss how HEADCO output should be used in assessments of site hydrology. The document should be revised to distinguish between alternative nomenclature for "standard hydraulic head" and similar terms and to discuss appropriate uses of program output in assessments of site hydrology.

HEADCO can be used to calculate standardized formation pressure, corrected observed hydraulic head, and standardized hydraulic head. Previous hydrologic assessments at Hanford have used alternative terms such as "equivalent freshwater head" and "environmental head," which are not discussed in the HEADCO document. The HEADCO document's discussion of program output is ambiguous because it does not compare terms calculated using the program with terms used in previous assessments. For example, the document does not clearly distinguish between "standard hydraulic head" and "equivalent freshwater head."

To avoid potential confusion and unintentional misuse of HEADCO output, therefore, the document should be revised to (1) define output terminology and compare it with terms used in previous assessments, (2) describe appropriate uses of output from the program, and (3) discuss the nature and magnitude of uncertainties associated with calculated values of standardized formation pressure and hydraulic head. These objectives could be accomplished by including assessments of water levels and heads from the Hanford Site as examples of appropriate use.

References to Supporting Assessments

Numerous sections of the HEADCO document mention assessments that support the development of the HEADCO program or its application at BWIP. The HEADCO document, however, does not reference or provide these assessments. The document should be amended to reference calculations and other assessments that support the HEADCO program.

The HEADCO document provides detailed discussions of the theoretical basis for the HEADCO program. Throughout these discussions, the document mentions analyses used to support the development of the program but does not reference these analyses or indicate their availability. For example, Section 3.1.2 presents third-order polynomial equations that describe the relationships between temperature, pressure, and the specific weight of water. The equations were apparently developed by RHO based on data contained in three references. The HEADCO document, however, does not reference a document that describes the formulation of these equations. A similar lack of referencing occurs in sections 3.1.1 (non-linear relationship of the specific weight of distilled water and temperature; range of specific weights of groundwater at the Hanford Site), 3.1.3 (development of the salinity vs. density relationship; assertion that different water chemistries will not significantly affect the relationship between specific weight and total dissolved solids concentration), 3.1.5 (assertion that multi-phase conditions do not exist in non-flowing wells), 3.2.1 (barometric efficiencies at Hanford), 3.2.2 (magnitude of earth tide responses at Hanford), 4.1.1.1 (1) (identification of temperature gradient equations for boreholes at the Hanford Site), 4.1.1.1 (2) (selection of the 10-foot depth increment), and 4.1.1.1 (6) (basis for the convergence criterion of 5.0E-4 lb/ft^3).

The HEADCO document should be revised either to incorporate the assessments used in the development of HEADCO or to reference appropriate documents.

Validation

The document attempts to validate the HEADCO program by comparing observed downhole pressures with pressures calculated using HEADCO. Documentation of the HEADCO validation is insufficient because it omits important details of the experimental configuration, collection of data, and application of the program. In addition, this validation attempt does not fully test the ability of the program to correct for variable densities caused by temperature, pressure, and salinity variations.

The HEADCO document describes a test case that was used to assess the accuracy of pressure and head values calculated using HEADCO. This case consists of a field evaluation of laboratory-calibrated quartz pressure probes in DC-8, where each probe was individually lowered into the borehole to a specified depth below the land surface. RHO then compared HEADCO-calculated pressure values with observed pressures. Based on this comparison, RHO concluded that HEADCO accurately calculated downhole formation pressures.

The validity of this comparison, however, cannot be determined because it is not documented in sufficient detail to allow an independent reviewer to verify the comparison. For example, the document does not describe how pressures were calculated for comparison with observed pressures and what input parameters were assumed in the HEADCO calculations (e.g., earth tidal effects, barometric efficiency, depth to the top of the formation).

In addition, the test case does not fully test the capabilities of the HEADCO program to accommodate significant variations in temperature, pressure, and salinity gradients in a variety of borehole configurations. RHO recognizes the need for additional validation of the program in the last paragraph of Section 6 on page 61.

DOE needs to demonstrate that the HEADCO program accurately corrects and converts field measurements of pressures and heads to standardized formation pressures and hydraulic heads. To accomplish this objective, DOE should validate the HEADCO program by using several test problems designed to test the capabilities and sensitivities of the program to variations in temperature, pressure, and salinity gradients, as well as external stresses. The test problems should include both problems with analytical solutions (verification problems) and empirical test problems based on reliable field information (validation problems). The HEADCO document should then be revised to either reference these validation/verification problems or include them in Section 6.

Limitations

The HEADCO program is limited because it does not account for vertical fluid density variations caused by changes in total dissolved solids concentration within a borehole. HEADCO assumes that the entire column of water in a borehole has the same concentration of total dissolved solids, so water densities are assumed to be independent of concentration changes within the fluid column. DOE should assess the significance of this limitation by validating the program using empirical data from boreholes in which total

dissolved solids concentrations vary significantly. If such variations represent conditions at the Hanford Site, DOE should consider enhancing HEADCO by modifying the program to accept a salinity profile (total dissolved solids concentration as a function of depth) rather than just a constant salinity value.

Additional Comments

1. The HEADCO document is generally consistent with NRC's Final Technical Position on Documentation of Computer Codes for High-Level Waste Management (NUREG-0856). Consistency with the position could be enhanced by amending the HEADCO document to include (1) more-detailed descriptions of subroutine functions and execution and (2) flow charts of the program structure and substructure.

2. The HEADCO document should reference procedures that RHO uses to correct field measurements (as described in Section 3.0, pg. 7) for instrument error and borehole deviation. According to the document, the use of these procedures is necessary prior to application of the HEADCO program.

3. Uncertainty in temperature measurements may cause significant uncertainties in hydraulic heads calculated using HEADCO. Section 3.1.1 states that an uncertainty of ±0.5°F associated with absolute temperature measurements corresponds to an uncertainty of ±0.25 lbf/in^2 for a 5000-foot fluid column. Assuming a constant standard density of borehole fluid, this uncertainty corresponds to an uncertainty of ±0.58 ft associated with calculated hydraulic heads. This uncertainty is significant compared with the low head differences measured at the Hanford Site. For example, a 0.25-foot head difference (10/85) exists across more than 590 feet at DC-22 between the Cohassett and Umtanum flow tops. In light of the low vertical differences in hydraulic heads, head differences introduced by temperature measurement uncertainties must be recognized in assessments of the direction and magnitude of vertical hydraulic gradients.

4. Section 3.1.3 uses non-standard notation for parts per million (ppm). On page 18, the abbreviation "p/m" is used apparently in place of ppm. The non-standard notation is ambiguous and should be removed from the text.

5. Section 5.2 incorrectly references figures 7 through 11 rather than figures 9 through 13 to provide the basic pressure and hydraulic head equations for different borehole configurations.

6. There are two significant errors in Section 3.2.3 "Gravitational Acceleration Variation." The document incorrectly states that, for elevations above mean sea level (MSL), free-air corrections are subtracted from the calculated theoretical gravitational acceleration at MSL for a given location (cf. pg. 27). Page 29 incorrectly states that the simple Bouguer correction would be added under the same conditions. For positive elevations, the free-air correction should be added and the Bouguer correction subtracted from the theoretical gravitational acceleration at MSL (Dobrin, 1960, pg. 230).

REFERENCE: Dobrin, M. B., 1960. Introduction to Geophysical Prospecting. New York, New York: McGraw-Hill Book Company, Inc.

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February 13, 1986
Contract No. NRC-02-85-008
Fin No. D-1020
Communication No. 31

Mr. Jeff Pohle
Division of Waste Management
Mail Stop SS-623
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

RE: BWIP

Dear Jeff:

I am enclosing a review of the following document:

1. Spane, F.A., Jr., and Mercer, R.B., 1985, HEADCO: A Program for Converting Observed Water Levels and Pressure Measurements to Formation Pressure and Standard Hydraulic Head: Rockwell Hanford Operations, RHO-BW-ST-71 P.

If you have any questions concerning these reviews, please call.

Sincerely,

Gerry V. Winter

Gerry V. Winter

GVW:sl

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WMGT DOCUMENT REVIEW SHEET

FILE #:

BWIP #: RHO-BW-ST-71 P

DOCUMENT: HEADCO: A Program for Converting Observed Water Levels and Pressure Measurements to Formation Pressure and Standard Hydraulic Head: 1985, Spane, F.A. Jr., and Mercer, R.B.

REVIEWER: Williams and Associates, Inc.

DATE REVIEW COMPLETED: February 10, 1986

ABSTRACT OF REVIEW: APPROVED BY: Roy E. Williams

This report presents a program (HEADCO) for converting static water level and pressure measurements to formation pressure and standard hydraulic head for conditions of variable fluid density. We find no significant problems with the report under review.

BRIEF SUMMARY OF DOCUMENT:

The abstract for the report under review describes adequately the contents of the report. We include the abstract verbatim for the summary of this document.

"Static water-level and fluid pressure measurements are commonly converted in hydrologic studies to formation pressure and hydraulic head, which are used to determine groundwater flow characteristics of aquifer systems. While the direct use of field measurements is usually adequate for determining formation pressure and hydraulic head for shallow flow systems (i.e., <1,000 ft), corrections and conversion parameters must be used to properly account for fluid-column density effects, which commonly occur with deep systems.

This report presents a program, HEADCO, for converting static water-level and pressure measurements to formation pressure and standard hydraulic head. The HEADCO program corrects field

measurements for the effects of fluid-density variation and selected external stresses. Factors that affect density of the fluid column, in which field measurements are made, include temperature, pressure, salinity, suspended solids, and multiphase conditions. External stresses examined in HEADCO include barometric and earth tide fluctuations, and gravitational acceleration variation.

A program description and procedures for converting field measurements obtained using field test arrangements commonly employed in the Basalt Waste Isolation Project field program are provided in this report. The report includes user instructions and an illustrative test example. Results of a field example comparison are also provided. This comparison examines observed and HEADCO-calculated pressures for 30 pressure probes recently calibrated in a laboratory and tested under field conditions at borehole DC-8. The test case and field example comparisons indicate that HEADCO provides accurate estimates of formation pressure and standard hydraulic head that are well within the accuracy range of downhole pressure-measuring instrumentation."

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

This report is important to the Waste Management Program because hydraulic gradients are essential to the determination of travel time and direction of groundwater flow at the BWIP site. The magnitude of the vertical and lateral gradients apparently is quite small. Differences in fluid density can affect the apparent hydraulic heads in the observation wells and piezometers located on the Hanford site. It is imperative that the relationship of these measured heads be compared on an appropriate basis due to the variable density of the fluids contained within these observation wells and piezometers. This report documents a procedure developed by Rockwell Hanford Operations for the interpretation of field data with respect to variable fluid density. The report also contains information and processes that will take into account external stresses such as those created by barometric and earth tide fluctuations as well as gravitational acceleration variations.

PROBLEMS, DEFICIENCIES, OR LIMITATIONS OF REPORT:

We do not find any deficiencies in the report under review. We do recognize a limitation of the program contained in this report. The program is designed to take into account variable fluid densities created by such things as temperature and

dissolved solids. The baseline density that is used in the program assumes that the fluid column contains a water of equivalent density based on essentially total dissolved solids content. This limitation is a restriction on the usefulness of the program if the fluid column in a piezometer should not contain a single density fluid based on TDS. We find this limitation a point worth noting but not worth criticizing at this time. It should be easy enough for Rockwell Hanford Operations to sample and test the water quality in the piezometers (which they do periodically) and boreholes to ascertain whether the borehole contains a variable density fluid due to a variable TDS content. If these boreholes do contain such a variable density fluid then the program should be altered to accommodate this aspect of data interpretation.

The multi piezometer completions that currently are in place (DC-19, -20, and -22) are, with two exceptions, filled with Hanford System water. This constant density water is different than that found in the basalt flow tops monitored in these piezometers. Two exceptions occur. The Umtanum piezometer in DC-19 was air-lift pumped for testing thermal effects on the adjacent piezometers in the same borehole. This piezometer, as a result, contains the Umtanum water. We believe this piezometer should contain water with a constant TDS content that is Umtanum water.

The second piezometer that may not have Hanford system water for its full depth is in cluster DC-20. A crimp formed in the piezometer tubing during the placement of the piezometers at cluster DC-20C. The Sentinel Gap piezometer string was dropped inadvertently and fell to a depth of 1,754 feet. A crimp was found in the Cohassett piezometer at a depth of about 1,754 feet. Rockwell attributes this crimp to the falling piezometer. The crimp prevented the placement of various equipment at the seating nipple near the bottom of the Cohassett piezometer string. This crimp prevented Rockwell Hanford Operations from developing this piezometer in the same manner as the other piezometers in the other clusters were developed. The standard development procedure consisted of flushing the tubing with detergent and water after setting a plug in the seating nipple. Fresh Hanford System water was then used to flush the tubing to insure that the tubing was clean after emplacement activities. Obviously this tubing could not be cleaned and filled with Hanford System water down to the seating nipple. This last exception could create problems with the program because we believe that the Cohassett piezometer would not contain Hanford System water throughout its total depth.

The field example problem (p. 59-61) compares measured and observed fluid pressures. The comparison of pressures indicates that the range in pressure differences is +0.6 to -0.8 lb F/in^2

abs with fluid densities that are not significantly different. We suggest that the HEADCO program be applied to an alternate field example if possible. This alternate field example should involve a fluid with a markedly different fluid density; this alternate field example will provide an upper bound on the sensitivity of the correction procedures.

TERRA THERMA, INC.
WATER CONSULTANTS AND ENGINEERS
8341 S. Sangre de Cristo Rd., Suite 6, Littleton, CO 80127 (303) 973-7492

December 31, 1985

Mr. Jeffrey Pohle, Project Officer
Geotechnical Branch
Division of Waste Management
U.S. Nuclear Regulatory Commission
MS 623 - SS
Washington, DC 20555

RE: "HEDCO: A Program for Converting Observed Water-Levels and Pressure Measurements to Formation Pressure and Standard Hydraulic Head".

Dear Jeff:

An initial review of the HEDCO document was made by Fred Marinelli of Terra Therma prior to the December BWIP meeting in Richland. Since a limited review of this document can not validate the model code, Mr. Marinelli concentrated on the logic and philosophy behind the model. Our preliminary comments are listed below.

1. Generally, the HEDCO program seems to be a reasonable approach for addressing the various affects on the determination of heads and therefore gradients. The program corrects for variations in temperature, salinity, water compressibility, barometric pressure, and gravitation.

2. The primary concern with the logic of the document is that only a single (constant) value of salinity can be assumed for the entire water column within the borehole. If ionic diffusion takes place between the water column and the formation and/or within the water column itself, it is possible that fluid salinity within the borehole may vary with depth. Thus, we would recommend that HEDCO be modified to incorporate a salinity profile (rather than assuming a constant value). This modification can probably be made by DOE with relatively few programming changes to the original computer code.

In order to validate the HEDCO program, one of several approaches can be used. The most straight forward approach would be to obtain a copy of the code, run the program until familar with it's operation, and run sample problems. However, because of the high cost of such an approach, we propose to create 4-6 problems, using various temperature, salinity, and pressure relationships, and submit them to DOE to be run on HEDCO. The problems would be designed so that relatively simple analytical solutions can be made for each linear relationship, and/or empirical measurements from real case-studies can be used to validate HEDCO's solutions. The test problems submitted to DOE, in many cases, would specify exaggerated relationships in order to evaluate the sensitivity and accuracy of the numerical results to temperature, salinity, pressure, etc. With the expenditure of a minimal amount of time, we feel that

HEDCO can be tested and validated adequately, keeping in mind that HEDCO is a computing program rather than a predictive model.

Our estimate of time and expenses for performing this task, including development of test cases and solutions, and report preparation, are as follows:

TASK: CREATE AND ANALYZE TEST PROBLEMS FOR HEDCO

PERSONNEL

Michael Galloway..	8	hours	@	$53.90	$ 431.20
Fred Marinelli....	32	hours	@	$37.50	$ 1200.00
Clerical/Drafting.	4	hours	@	$20.00	$ 80.00
Subtotal.....					$ 1711.20

EXPENSES

Mileage.....	0	miles	@	$.00	$ 0.00
Telephone.....	0	calls	@	$0.00	$ 0.00
Copies.....	100	Copies	@	$.10	$ 10.00
Computer.....	15	hours	@	$ 5.00	$ 75.00
Word Processor....	5	hours	@	$5.00	$ 25.00
Per Diem/lodging..	0	days	@	$ 0.00	$ 0.00
Misc. Expenses....					$ 0.00
Subtotal.....					$ 110.00

ESTIMATED TOTAL TIME AND EXPENSES $ 1821.20

If you have any questions or we can provide any additional information, please contact the undersigned.

Sincerely,
TERRA THERMA, INC.

Michael Galloway

Michael Galloway
Project Manager, BWIP

cc Mark Logsdon
Project Manager, NWC