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Camp Humphreys, Korea, Groundwater Assessment

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Final report

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Abstract: This study was conducted to (a) determine the current groundwater production capacity using the pumping data from 21 production wells; (b) estimate potential recharge from rainfall and surface water sources; (c) determine total groundwater availability using precipitation and soil data, and predict the future water use assuming a potential increase of camp population from 7,500 to 40,000; and (d) estimate water availability in a land zone adjacent to the Camp Humphreys area. Several modeling approaches were evaluated for the preliminary calculation of water budget at the site. Among these approaches, the Hydrologic Evaluation of Landfill Performance computer program suited the limited hydrogeological data that were available for the site. The recharged and stored water in the subsurface of the existing Camp Humphreys appears to be adequate for the current camp population usage. This assessment's model conditions predicted a potential recharge of nearly 4 billion gallons per year to the aquifer beneath land adjacent to the west side of Camp Humphreys and terminating at the Anseong River. If all of this aquifer recharge were available for withdrawal, it would meet future population needs for the expansion of Camp Humphreys (assuming a population of 40,000). However, the actual availability of this estimated aquifer recharge to new supply wells constructed in the adjacent land will depend highly on the density and hydrogeologic characteristics of bedrock fracturing, overlying soil and land use conditions, and groundwater quality conditions.

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Preface

Danny W. Harrelson of the Geotechnical and Structures Laboratory (GSL) and Dr. Mansour Zakikhani of the Environmental Laboratory (EL), both of the U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS, conducted the work and prepared this report, along with Mathew J. Waterbury, formerly of the U.S. Army Engineer District (USAED), Far East. Technical reviews of the report were provided by Drs. Maureen K. Corcoran and Joseph B. Dunbar of GSL.

This work was funded by the USAED, Far East, in Seoul, Korea. The work was conducted under the general supervision of Dr. Corcoran, Acting Chief, Engineering Geology and Geophysics Branch; Dr. Robert L. Hall, Chief, Geosciences and Structures Division; Dr. William P. Grogan, Deputy Director, GSL; and Dr. David W. Pittman, Director, GSL. Dr. Richard E. Price was Chief of the Engineering Processes and Effects Division, EL, and Dr. Beth C. Fleming was Director, EL.

COL Richard B. Jenkins was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
acre-feet	1,233.5	cubic meters
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
hectares	1.0 E+04	square meters
inches	0.0254	meters
miles (U.S. statute)	1,609.347	meters
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters
square miles	2.589998 E+06	square meters
square yards	0.8361274	square meters

1 Introduction

The U.S. Army Engineer Research and Development Center (ERDC) in Vicksburg, MS, performed a preliminary groundwater resources assessment for Camp Humphreys (CH) (Figure 1) and a land zone adjacent to CH (Figure 2) in the Republic of Korea. Camp Humphreys is located about 35 miles south of Seoul, just to the southeast of Asan Bay. There is a small mountain range about 7 miles south of Camp Humphreys with tops to 958 ft. The Ansong River flows from the east to west toward the West Sea. About 12 miles west of Camp Humphreys, the river widens and empties into the Asan Bay, near Koon-ni Range. The immediate area around Camp Humphreys is mostly agricultural and consists mainly of rice fields. There are some rolling hills in the vicinity, but for the most part the elevations are less than 150 ft.

This effort is part of the Camp Humphreys Comprehensive Master Plan (CHCMP). The adjacent land area is located northwest of CH and was investigated to determine potential groundwater availability for future use. The input data and calculated results are summarized in Tables 1 and 2, respectively. The U.S. Army Engineer District, Far East, Seoul, Korea, provided the measured data of the site that were used in the calculations. The main purposes of this study were to

1. Determine the current groundwater production capacity using the pumping data from 21 production wells.
2. Estimate potential recharge from rainfall and surface water sources.
3. Determine total groundwater availability using precipitation and soil data, and predict the future water use assuming a potential increase in camp population from 7,500 to 40,000.
4. Estimate water availability in a land zone adjacent to CH.

A numerical model was selected to perform the above objectives. The model estimated potential recharge to the subsurface using precipitation and surface water data.

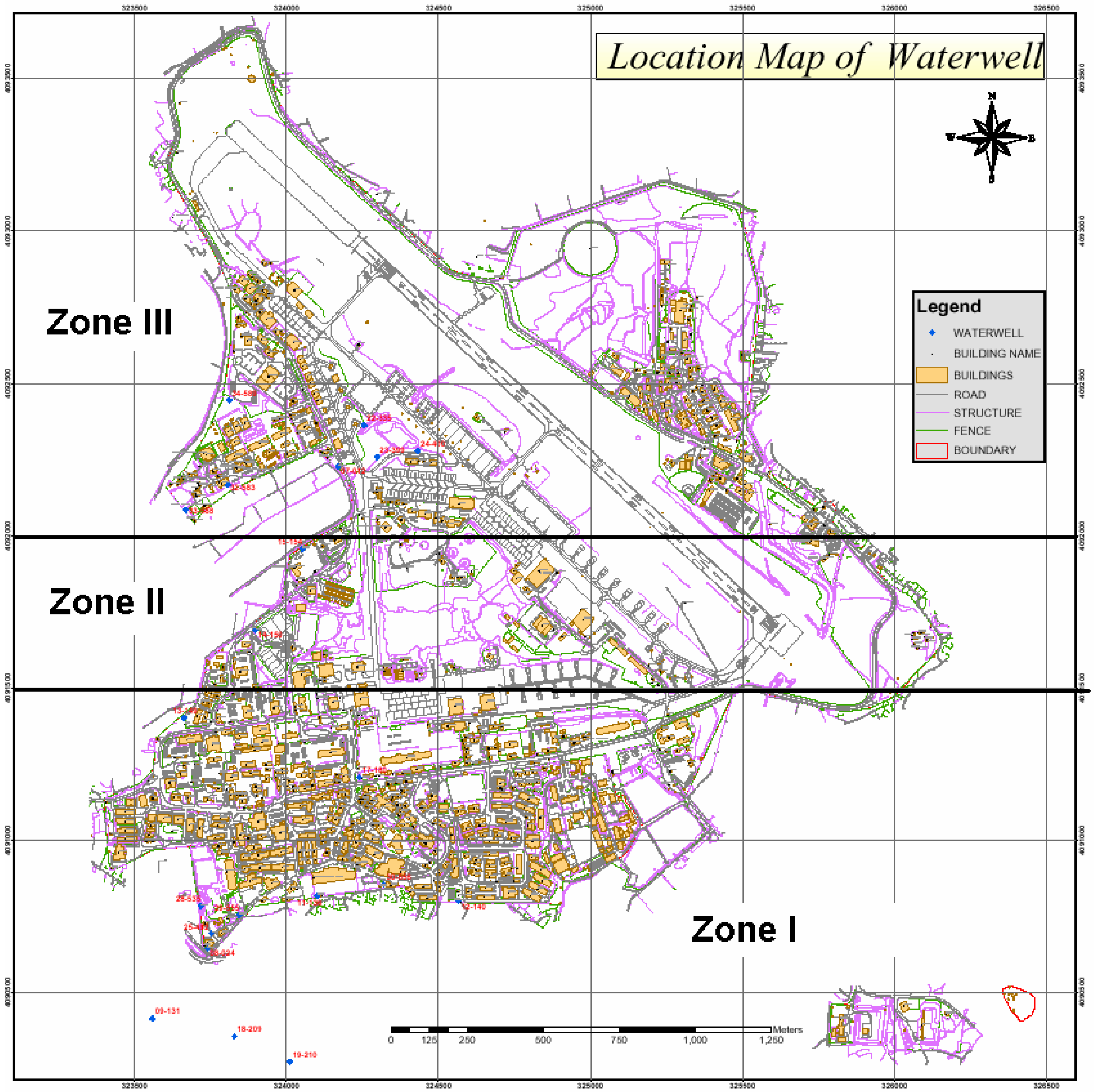

Figure 1. Map of Camp Humphreys, location of water wells, and modeling zones.

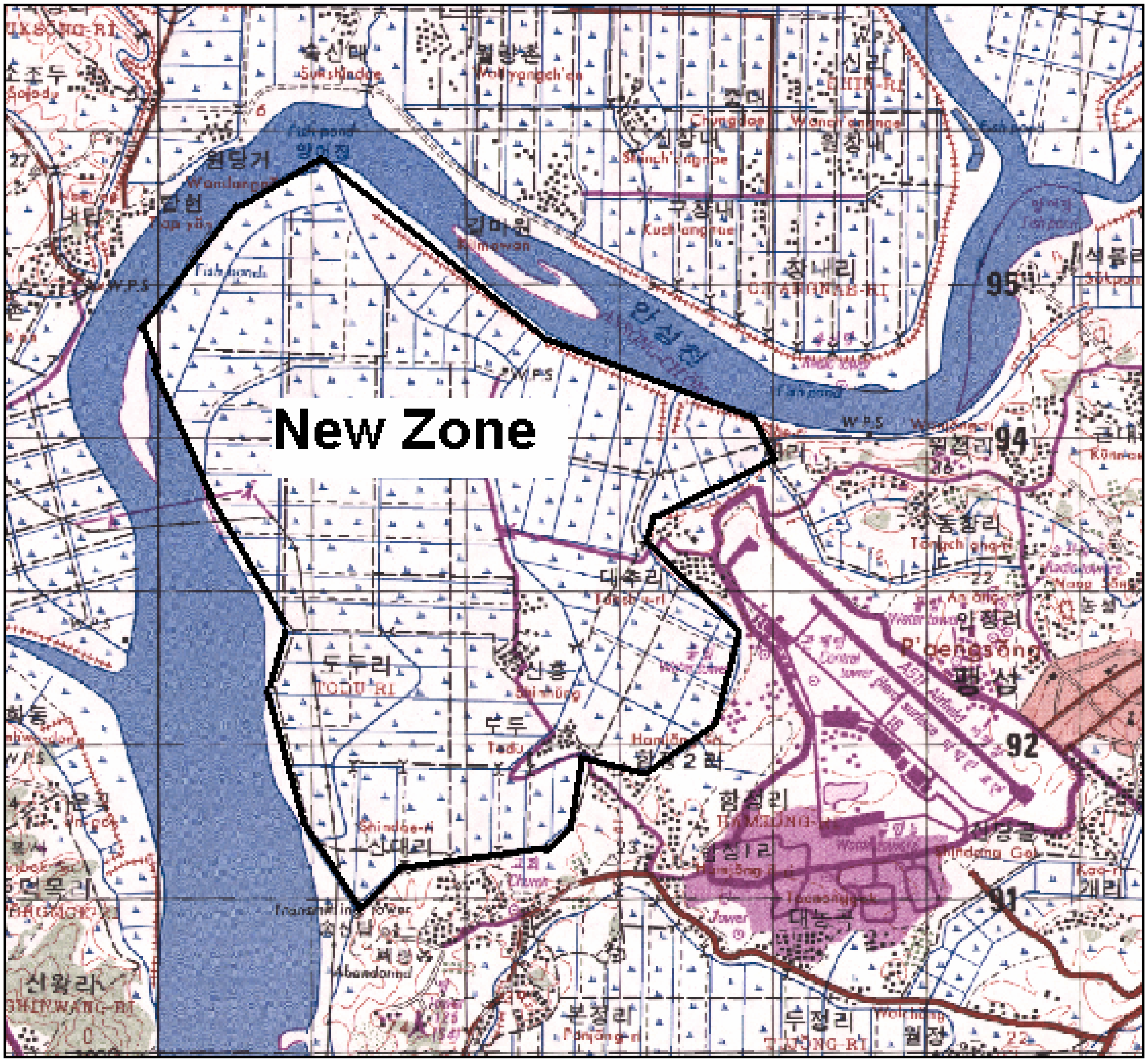

Figure 2. Land zone (approximate) northwest of Camp Humphreys bounded by black solid line.

Table 1. Monthly well production for Camp Humphreys (1,000 gal)

No.	Nov 02	Dec 02	Jan 03	Feb 03	Mar 03	Apr 03	May 03	Jun 03	Jul 02	Aug 03	Sep 03	Oct 03	Nov 03	Total
Well 7	1,776	2,174	2,044	2,305	1,891	1,886	1,522	814	1,747	1,984	2,003	1,769	1,859	23,774
Well 8	960	458	1,081	1,164	1,116	1,212	867	936	908	620	575	546	358	10,801
Well 9	1,679	1,324	1,554	1,602	1,359	1,315	1,860	1,496	1,469	1,240	381	1,293	0	16,572
Well 11	960	774	207	0	700	270	746	781	894	837	892	869	844	8,774
Well 12	1,199	1,146	1,327	1,375	1,388	1,448	1,094	1,009	220	220	212	186	476	11,300
Well 13	638	703	858	791	925	902	691	712	323	323	312	217	0	7,395
Well 14	3,144	3,642	3,415	3,280	3,241	3,619	2,511	2,768	3,521	3,521	3,265	3,219	3,215	42,361
Well 15	1,035	1,289	1,131	1,263	1,023	780	773	858	1,551	961	117	0	0	10,781
Well 17	1,061	1,097	1,447	892	1,006	1,187	920	1,151	1,065	1116	1121	996	1,180	14,239
Well 18	2,333	3,539	2,602	2,885	2,762	3,082	2,237	2,339	2,913	2,666	2,408	2,617	1,174	33,557
Well 19	2,130	324	1,082	1,226	1,178	1,652	1,163	1,216	1,183	1,085	969	1,091	1,065	15,364
Well 22	2,299	2,376	2,704	2,496	2,480	4,363	3,012	600	15	2,015	3,360	5,347	4,045	35,112
Well 23	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Well 24	1,980	1,147	1,240	1120	534	1033	821	1,098	1,179	310	63	0	908	11,433
Well 25	2,306	3,338	2,533	2,846	3,152	3,942	2,713	2,850	3,172	2,232	2,468	2,418	2,202	36,172
Well 28	2,071	1,691	1,054	1,041	1,524	1,408	1,395	840	1,344	1,209	1,209	999	701	16,486
Well 29	1,740	2,306	1,501	1,136	1,414	1,380	1,426	1,490	1,834	1,488	1,860	1,552	979	20,106
Well 30	3,147	3,058	2,644	2,574	2,910	2,632	1,924	2,709	2,855	2,790	2,621	2,177	2,598	34,639
Well 32	2,878	3,576	3,924	3,614	4,030	4,335	8,981	7,870	9,638	7,936	7,402	7,388	7,616	79,188
Total	33,336	33,962	32,348	31,610	32,633	36,446	34,656	31,537	35,831	32,553	31,238	32,684	29,220	428,054

Table 2. Camp Humphreys preliminary groundwater budget

Modeling Zone	Well Number	Well Depth, ft	Depth to Water, ft	Year	Run Hours	Yearly Well Production, gal x 1000[1]	Yearly Recharge, gal x 1000[2]	Water Budget, gal x 1000[3]
1	8-24	315	161	2002	23	9,841	148,582	
1	9-131	320	134	2003	16	14,893		
1	11-136	345	166	2003	10	7,814		
1	12-140	212	57	2003	20	10,101		
1	13-149	205	55	2003	5	6,757		
1	17-180	420	102	2003	15	13,178		
1	18-209	341	162	2003	23	31,224		
1	19-210	300	174	2003	10	13,234		
1	25-492	470	192	2003	20	33,866		
1	26-000		120	1992		0		
1	28-535	486	176	2000	15	14,415		
1	29-531	600	177	2003	15	18,366		
1	30-556	610	176	2003	20	31,492		
2	14-150	370	75	2003	10	39,217	263,244	
2	15-154	404	68	2003	5	9,746		
3	7-12	340	87	2002	16	21,998	316,571	
3	22-335	731	104	2003	20	32,813		
3	23-399	399	82	2003	0	0		
3	24-400	440	160	2003	15	9,453		
3	32-000	505	81	2003	17	76,310		
3	33-000	280	58	2003		0		
3	34-000	194	32	2001		0		
Current Zone						394,718	728,397	333,679
New Zone						Presently None	3,766,516	

[1] Based on 2002 records provided by Camp Humphreys Department of Public Works.

[2] Based on HELP model using 2002(?) meteorological data provided by Korea Institute of Geoscience and Mineral Resources (dated 2003) and Far East District's geotechnical borehole data.

[3] Water budget (gal x 1000) = Yearly recharge – Yearly well production for November 2003.

2 Modeling

Several modeling approaches were evaluated for the preliminary calculation of the water budget at the site. Among these approaches, the Hydrologic Evaluation of Landfill Performance (HELP)[1] computer program suited the limited hydrogeological data that were available. The HELP program is a quasi-two-dimensional hydrologic model of water movement across, into, through, and out of a subsurface of soil and geologic formation. The model accepts weather, soil, and design data and uses solution techniques that account for the effects of surface storage, snowmelt, runoff, infiltration, evapotranspiration, vegetative growth, soil moisture storage, and leakage through soil. The program was developed to conduct water balance analyses. As such, the model facilitates rapid estimation of the amounts of runoff, evapotranspiration, liner leakage, and soil storage. The primary purpose of the model is to assist in the comparison of design alternatives as judged by their water balances. The model, applicable to hydraulically open, partially closed, and fully closed sites, is a tool for both designers and permit writers.

Water balance calculation in HELP model

The hydrologic processes modeled by the HELP model are divided into two categories: surface processes and subsurface processes. The surface processes modeled are snowmelt, interception of rainfall by vegetation, surface runoff, and evaporation of water. The subsurface processes modeled are evaporation of water from the soil and plant transpiration. Infiltration into the subsurface is determined indirectly from a surface-water balance. Infiltration is assumed to equal the sum of rainfall, minus the sum of runoff, surface storage, and surface evaporation. A rainfall-runoff relationship is used to determine the runoff. The rainfall-runoff process is modeled using the U.S. Department of Agriculture Soil Conservation Service (SCS) curve-number method. The SCS procedure was developed from rainfall-runoff data for large storms on small watersheds. Surface evaporation is then computed. The rate of evapotranspiration from a land surface is a function of solar radiation,

[1] Schroeder, P. R., N. M. Aziz, C. M. Lloyd, and P. A. Zappi. 1994. The Hydrologic Evaluation of Landfill Performance (HELP) model: User's guide for version 3. EPA/600/R/94/168a. U.S. Environmental Protection Agency, Cincinnati, OH.

temperature, humidity, vegetation type and growth stage, water retained on the surface, soil water content, and other soil characteristics. The rainfall that does not run off or that evaporates is assumed to infiltrate into the subsurface. The first subsurface processes considered are evaporation from the plant transpiration and soil from the evaporative zone of the upper soil subprofile. The program performs a water balance on each segment to determine the water storage, subsurface inflow, and moisture content and material characteristics.

Modeling approach

For the hydrologic calculation, CH was divided into three hydrologic zones (Figure 1) representative of the land surface conditions (building, vegetation covers, etc.). The HELP program was used to estimate the recharge for each of the three zones. Several assumptions were used to complete the calculations, including the following:

1. Precipitation is uniform over each zone of the calculation.
2. The subsurface soil has four lithologic layers (lean clay, silt, fat clay, and silty clay) (Figure 3).
3. The subsurface was assumed to be porous media.
4. Surface soil conditions were assumed using the GIS site maps provided by the Korea Institute of Geoscience and Mineral Resources' 2003 hydrogeologic investigation of the Camp Humphreys vicinity.
5. The primary source of water for the production wells is from area precipitation recharge (calculated by the model for zones of interest).
6. Pumping data used were monthly well production values for November 2003.
7. Water loss from the distribution water lines was considered negligible and was not used as part of the water budget calculations.

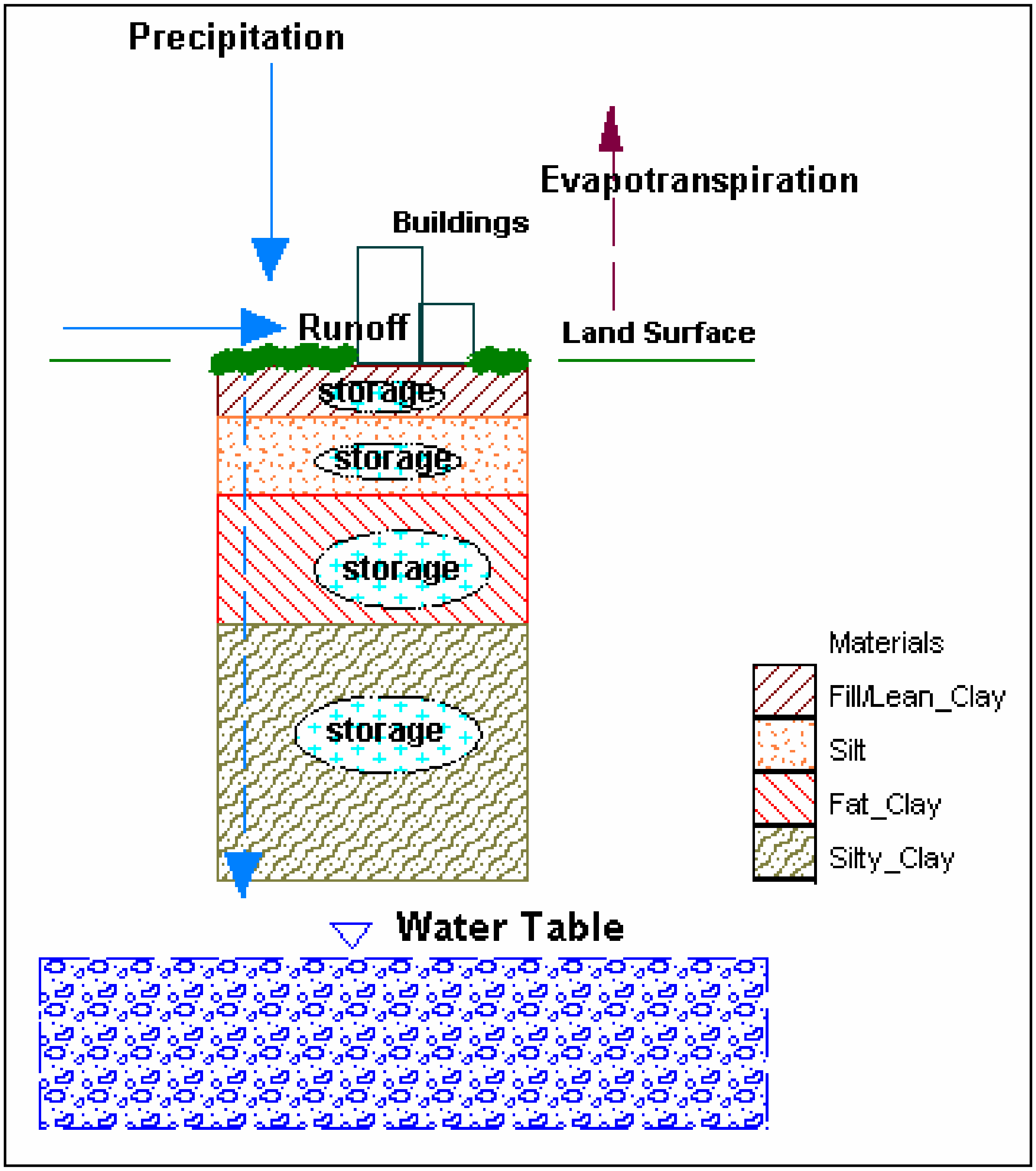

Figure 3. Schematic of lithologies used in the modeling zones.

Potential Capacity of New Areas

Geologic analysis of the region indicates that a tectonic extension of the Chugaryound Fault Belt trends north-northeast into the CH area. This fault belt (and a west-northwest-trending shear zone) has produced fracture patterns in the rocks that are believed to be the major source of groundwater in the CH areas.[1] These fracture patterns also extend into the

[1] Unpublished data report, May 2004, Preliminary Groundwater Availability Assessment. Camp Humphreys Real Property Master Plan (G&E 03-065). U.S. Army Engineer District, Far East, Seoul, Korea.

new areas northwest of CH and are interpreted be a potential source of potable water. The subsurface soil was subdivided into layers of a lean clay (CL), a silt layer (ML), a fat clay (CH), and a silty clay (SC) to simulate existing hydrologic conditions as accurately as possible.

To estimate the number of wells that will be constructed (needed) in the new acquired zone, the following assumptions were used: (a) the acquired zone has an area three times larger than the existing Camp Humphreys area; (b) the calculated available water based on the model is approximately 3,766,516 Kgal or about 3.7 MGD; (c) the population of the new zone will be 15,000, 22,500, or 30,000; (d) the existing population (7,500) at the Camp needs 1.2 MGD, the population level of 15,000 requires 2.3 MGD, the population level of 22,500 requires 3.4 MGD, the population level of 30,000 requires 4.5 MGD, and the population level of 40,000 requires 6.2 MGD.

A simple calculation indicates that the required numbers of wells for each of these population levels are 21, 40, 60, 79, and 98 wells, respectively. The initial estimated water in the acquired zone may be sufficient for all the future four levels of population growth. The calculated value of the available water in the acquired zone must be further evaluated using additional and more accurate field data and advanced modeling techniques. The numbers provided here are based on several assumptions and simple model calculations, as outlined above.

3 Summary

This report describes preliminary water budget calculations for Camp Humphreys and an adjacent land area. A numerical model called HELP was used in these calculations. The results, which should be used in the context of the modeling assumptions, indicated a limited source of subsurface water is still available for use by Camp Humphreys. The recharged and stored water in the subsurface of the existing Camp Humphreys appears to be adequate for the current camp population usage. This assessment's model conditions predicted that the existing Camp Humphreys supply wells withdraw approximately 54 percent of the water that recharges the bedrock aquifer beneath the current camp boundary. Although the rate of withdrawal does not exceed the recharge, future problems will likely be expected to lower water levels in existing water supply wells. These problems will be occur as the result of two major issues: (1) the proximity of existing pumping wells to each other causes excessive groundwater drawdowns (note that the water supply wells are located within about 40 percent of the current Camp Humphreys land area) and (2) the expected variability of meteorological conditions from year to year, which could at times create drought conditions. A modification of the pumping rates/frequency of the existing wells may be necessary to allow sufficient time for groundwater replenishments.

This assessment's model conditions predicted a potential recharge of nearly 4 billion gallons per year to the aquifer beneath land adjacent to the west side of Camp Humphreys and terminating at the Anseong River. If all of this aquifer recharge were available for withdrawal, it would meet future population needs for the expansion of Camp Humphreys (assuming a population of 40,000). However, the actual availability of this estimated aquifer recharge to new supply wells constructed in the adjacent land will depend highly on the density and hydrogeologic characteristics of bedrock fracturing, overlying soil and land use conditions, and groundwater quality conditions. The Korea Institute of Geosciences and Mineral Resources' 2003 hydrogeologic report of Camp Humphreys and vicinity indicates folding has created a local syncline that may enhance recharge into the fault and shear zones found in CH and the adjacent areas. A thorough hydrogeologic study of the site (such as the construction of test wells, performance of pumping tests, and evaluation of groundwater quality) is necessary to refine or confirm the results reported here.

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14. ABSTRACT

This study was conducted to (a) determine the current groundwater production capacity using the pumping data from 21 production wells; (b) estimate potential recharge from rainfall and surface water sources; (c) determine total groundwater availability using precipitation and soil data, and predict the future water use assuming a potential increase of camp population from 7,500 to 40,000; and (d) estimate water availability in a land zone adjacent to the Camp Humphreys area. Several modeling approaches were evaluated for the preliminary calculation of water budget at the site. Among these approaches, the Hydrologic Evaluation of Landfill Performance computer program suited the limited hydrogeological data that were available for the site. The recharged and stored water in the subsurface of the existing Camp Humphreys appears to be adequate for the current camp population usage. This assessment's model conditions predicted a potential recharge of nearly 4 billion gallons per year to the aquifer beneath land adjacent to the west side of Camp Humphreys and terminating at the Anseong River. If all of this aquifer recharge were available for withdrawal, it would meet future population needs for the expansion of Camp Humphreys (assuming a population of 40,000). However, the actual availability of this estimated aquifer recharge to new supply wells constructed in the adjacent land will depend highly on the density and hydrogeologic characteristics of bedrock fracturing, overlying soil and land use conditions, and groundwater quality conditions.

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