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*Geothermal Energy Development
in the Eastern United States*

**A PROGRAM FOR
CAPITAL RECOVERY ASSESSMENT
FOR THE HP-97 AND
OTHER DESK CALCULATORS**

KWANG YU

ROY VON BRIESEN

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THE JOHNS HOPKINS UNIVERSITY ■ APPLIED PHYSICS LABORATORY

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Johns Hopkins Road, Laurel, Maryland 20810
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Preface

The Johns Hopkins University Applied Physics Laboratory and the Center for Metropolitan Planning and Research support the Division of Geothermal Energy, U.S. Department of Energy, in the development of geothermal energy in the Eastern United States. In this role, many tools have been developed to assist in the analysis of the economics of the application of geothermal energy. This report documents one computer program that has proved useful. Other reports of interest are:

1. "Economic Evaluation Model for Direct Use of Moderate Temperature Geothermal Resources in the Northern Atlantic Coastal Plain," APL/JHU GEMS-003, QM-79-124, June 1979.
2. "GRITS: A Computer Program for the Economic Evaluation of Direct-Use Applications of Geothermal Energy," APL/JHU GEMS-008, QM-80-077, June 1980.

If you have questions, please contact the authors or Mr. F. C. Paddison, APL/JHU, (301) 953-7100, extension 591.

A Program for Capital Recovery Assessment
For the HP-97 and Other Desk Calculators

A desk calculator program for estimating the capital recovery period (Ref. 1) for a geothermal space heating system has been developed for use with the Hewlett Packard 97 calculator. The program can also be adapted to the Texas Instrument 59 with the PC-100 printer.

The program was developed to provide a simple economic model which could be used in various JHU/APL geothermal technical assistance projects. The program output is in the form of a listing which shows the years to pay off the geothermal space heating system (total capital investment and annual O&M cost) as a function of incremented grant fraction and annual oil price escalation rate as shown in Table 1. These data can then be plotted to show the trends of the incremented functions as shown in Figs. 1 and 2.

The program algorithm and assumptions are as follows:

Notations

1. $\$_0$ = the total capital layout at $t = 0$
2. f = the grant fraction, $0 \leq f \leq 1$, so that $\text{Grant} = f\$_0$
3. $(1-f)\$_0$ = the initial loan
4. γ = the loan interest rate (fraction) per year
5. G = the annual fuel savings in gallons realized by the Geothermal (=GT) system
6. $\$_{op}$ = the annual operational cost of the GT system
7. $\$_m$ = the annual maintenance cost of the GT system
8. c = the initial unit price of fuel (oil)
9. β = the oil price escalation rate (fraction) per year.

Assumption

Since $\$_{op}$ and $\$_{m}$ are both energy (and labor) intensive, we assume that they escalate at the same rate as the oil price.

Pay-Off Strategy

Pay off the debt with the net savings in fuel alone (one payment at the end of each year).

Net Fuel Savings

By assumption, the GT system maintenance and operational costs will track the oil price, and hence, the constant g defined by

$$g = (\$_{m} + \$_{op})/cG$$

gives the fraction of the gross fuel savings required by the GT system for operation and maintenance.

Thus, the net annual fuel savings is $(1-g)G$.

Problem

Determine the debt pay-off period N (years) as a function of all parameters described above; i.e.,

Determine

$$N = N(\$_0, f, \gamma, G, g, c, \beta)$$

Solution

Let S_k be the outstanding principal at the beginning of k -th year (we count from 0) then we have

$$S_k = [(1-f)\$_0 + (1-g)cG](1+\gamma)^k - (1-g)cG(1+\gamma)^k \sum_{n=0}^k \left(\frac{1+\beta}{1+\gamma} \right)^n$$

Hence when the debt is just paid off, we have

$$\frac{(1-f)\$_0 + (1-g)cG}{(1-g)cG} = \sum_{k=0}^N \left(\frac{1+\beta}{1+\gamma} \right)^k$$

To sum the right-hand side, we have two possibilities.

Case 1: $\gamma = \beta$ We have

$$N = \frac{(1-f)\$_0}{(1-g)cG}$$

Case 2: $\gamma \neq \beta$. Put $U = (1+\beta)/(1+\gamma)$. Then

$$N = \frac{\ln F}{\ln U} - 1$$

where

$$F = U - \frac{(1-f)(1-U)\$_0}{(1-g)cG}.$$

Allowed Ranges of Parameters

To insure the existence of solution, we need to examine the ranges of the parameters the pay-off period N depends upon.

Evidently, if $f = 1$, $N = 0$ (since there is no loan). So we examine the range $0 \leq f < 1$. Next, if $g \geq 1$, the "net-saving" is non-positive and hence the solution cannot exist.

We therefore assume $0 \leq f < 1$ and $0 < g < 1$. Clearly, if $\gamma \leq \beta$, the solution exists for all values of the parameters. So assume $\beta < \gamma$. Then $0 < U < 1$. From this we have

$$0 < F < U < 1.$$

Here, $U < 1$ holds by assumption. Next, $F < U$ portion is uninteresting since it is equivalent to $U < 1$. The only remaining requirement is $0 < F$ (since F appears as the argument of a logarithm), which gives

$$\frac{\gamma(1-f)\$_0 - (1-g)cG}{(1-f)\$_0 + (1-g)cG} < \beta \quad (< \text{by assumption}).$$

Thus the solution exists

- 1) If $f = 1$
- 2) If $0 \leq f < 1$, $0 < g < 1$, and either

$$(i) \quad \gamma \leq \beta$$

$$\text{or } (ii) \quad \gamma > \beta > \frac{\gamma(1-f)\$_0 - (1-g)cG}{(1-f)\$_0 + (1-g)cG}.$$

The model's economic simplicity is shown in the assumption and pay-off strategy; namely that the O&M cost escalates at the same rate as the oil price, and the payoff for the debt is done annually with the net savings in fuel alone. The algorithm at present is set up to let geothermal space heating replace an oil-fired system. With other fuels such as coal, gas, etc., an adjustment would have to be made to notation 5 for the units of fuel used and to notations 8 and 9 for the initial unit fuel price and the annual unit fuel escalation rate.

Program Design, Options and Use

The solution presented previously was coded so that the program would provide the pay-off periods corresponding to a range of β (the oil price escalation rate) as well as that of f (the grant fraction). The program structure was so chosen that f (resp. β) can be held constant while β (resp. f) is being incremented automatically. To update f (resp. β) and run through the β (resp. f) values, the user should hit the run/start key to stop the execution, and then depress the program key **A** (resp. **E**).

To use the program it is necessary to load the registers as follows prior to execution.

<u>Register Number</u>	<u>Value to be Entered</u>
0	$\$_0$
1	Δf (grant fraction increment)
2	$\Delta \beta$ (oil-price escalation rate increment)
3	γ
4	G
5	c
6	$g = (\$_m + \$_{op})/cG$
E	initial value (lower bound) of β
I	initial value (lower bound) of f

(The remaining registers are used by the program.)

*respectively

Once the registers are initialized, the program key ☐ C should be depressed to prepare the remaining registers. Then according to the discretion of the user, either ☐ A or ☐ E can be utilized as explained previously.

The user may encounter a situation where the error message is displayed. What this signals is that, with the given set of parameters, the (real-valued) solution does not exist, as discussed in "Allowed Ranges of Parameters." To get out of this mode without disturbing the automatic stepping of ΔB or Δf , press the run/stop key; a negative number will appear in the display. Then change the sign making this number positive, and press the run/stop key again to continue the program. The printed output from this interval will be meaningless and must be so noted on the output listing, as shown by an asterisk in Tables 1 and 2.

The output from ☐ A (or ☐ E) consists of two parts. The first part contains the content of all registers 0 through I. The second part contains groups of three items. The first item is the grant fraction f , the second being the oil price escalation rate B , and the final item the loan pay-off period (the solution) N (see Table 1).

An Example

As an example of the use of this program, we consider the following hypothetical problem.

A geothermal system is to replace an oil-based heating system which used 52,000 gals/yr of heating oil. The geothermal system is so designed that the oil usage by the peaking system (Ref. 4) is 2000 gal/yr. We assume that the capital investment for the system is \$800,000, financed at an interest rate of 7%/yr. Further, suppose:

the current selling price of oil = \$1.00/gal

the operating and maintenance cost = \$10,000/yr,

and that the GT system is eligible for some federal grant.

We wish to generate an array of solutions (where they exist) for the oil price escalation rates of 0 to 20%/yr at an increment of 5% per year, and a federal grant fraction of 0 through 30% at an increment of 10%. We then load the registers as follows:

<u>Register</u>	<u>Content</u>	<u>Remarks</u>
0	800,000	
1	.10	
2	.05	
3	.07	
4	50,000	net annual savings in oil
5	1.00	
6	.20	= 10,000/1 x 50,000
7 - I	0	

The program output obtained using the program option A is shown in Table 1 and plotted in Fig. 1. The option E output is the same thing rearranged (corresponds to the transposed "matrix"), which is shown in Table 2 and plotted in Fig. 2 for completeness.

This program was used in several JHU/APL technical assistance reports (Refs. 2 and 3) for DOE/DGE and has proved to be a most valuable tool.

References

1. JHU/APL Memo QM-80-043, "Capital Recovery Period," K. Yu, March 1980.
2. JHU/APL Letter CQO-2544 to W. L. R. Rice/U.S. DOE, "The Crisfield, Maryland Well and Geothermal Energy," F. C. Paddison, Nov 1979, to be reissued as "Technical Assistance Report No. 1, Geothermal Space Heating the Crisfield High School."
3. JHU/APL Memo QM-80-101, "Technical Assistance Report No. 4, Geothermal Space Heating Pittsville Middle/Elementary School, Pittsville, Maryland," R. von Briesen, K. Yu, June 1980.
4. JHU/APL Paper, "Technical Assistance - Hydrothermal Resource Application in the Eastern United States," to be presented at the Annual Geothermal Resources Council meeting September 1980.

Calculator Output from Option A

Part II is the Output using the Register Content

*No solution "N" is meaningless
Do not use

Fig. 1 A plot for output A.

Table 2

Calculator Output from Option E

Part I is the Register Content

Part II is the Output using the Register Content

Part I	800000.00	0		800000.00	0		800000.00	0
	0.10	1		0.10	1		0.10	1
	0.05	2		0.05	2		0.05	2
	0.07	3		0.07	3		0.07	3
	50000.00	4		50000.00	4		50000.00	4
	1.00	5		1.00	5		1.00	5
	0.20	6		0.20	6		0.20	6
	1.07	7		1.07	7		1.07	7
	0.00	8		0.05	8		0.10	8
	0.00	9		0.00	9		0.00	9
	800000.00	A		800000.00	A		800000.00	A
	0.93	B		0.93	B		1.03	B
	40000.00	C		40000.00	C		40000.00	C
	0.00	D		0.00	D		0.00	D
	0.00	E		0.00	E		0.00	E
	0.00	I		0.00	I		0.00	I
Part II	0.00	***		0.00	***		0.00	***
	* 0.00	***		0.05	***		0.10	***
	13.54	***		25.42	***		15.74	***
	0.10	***		0.10	***		0.10	***
	* 0.00	***		0.05	***		0.10	***
	19.91	***		22.25	***		14.44	***
	0.20	***		0.20	***		0.20	***
	* 0.00	***		0.05	***		0.10	***
	31.34	***		19.26	***		13.10	***
	B = 0.30	***		0.30	***		0.30	***
	f = 0.00	***		0.05	***		0.10	***
	N = 57.82	***		16.44	***		11.70	***

*No solution "N" is meaningless
Do not use

Table 2 (continued)

800000.00	0	800000.00	0
0.10	1	0.10	1
0.05	2	0.05	2
0.07	3	0.07	3
50000.00	4	50000.00	4
1.00	5	1.00	5
0.20	6	0.20	6
1.07	7	1.07	7
0.15	8	0.20	8
0.00	9	0.00	9
600000.00	A	600000.00	A
1.07	B	1.12	B
40000.00	C	40000.00	C
0.00	D	0.00	D
0.00	E	0.00	E
0.00	I	0.00	I
0.00	***	0.00	***
0.15	***	0.20	***
12.09	***	10.05	***
0.10	***	0.10	***
0.15	***	0.20	***
11.26	***	9.43	***
0.20	***	0.20	***
0.15	***	0.20	***
10.38	***	8.77	***
0.30	***	0.30	***
0.15	***	0.20	***
9.43	***	8.05	***

Fig. 2 A plot for output E.

APPENDIX

Listing of HP-97 Program

001	*LBLC	21 13	042	RCL8	36 08	083	RCLA	36 11
002	RCLC	36 15	043	+	-55	084	RCLC	36 13
003	RCL2	36 02	044	X=Y	-41	085	=	-24
004	-	-45	045	=	-24	086	*LBL3	21 03
005	ST08	35 08	046	ST08	35 12	087	ST0D	35 14
006	RCL1	36 46	047	1	01	088	SPC	16-11
007	RCL1	36 01	048	RCL9	36 09	089	RCL9	36 09
008	-	-45	049	-	-45	090	PRTX	-14
009	ST09	35 09	050	RCL0	36 00	091	RCL8	36 08
010	1	01	051	x	-35	092	PRTX	-14
011	RCL6	36 06	052	ST0A	35 11	093	RCLD	36 14
012	-	-45	053	0	00	094	PRTX	-14
013	RCL5	36 05	054	ST0D	35 14	095	F00	16 23 00
014	x	-35	055	SPC	16-11	096	GT04	22 04
015	RCL4	36 04	056	SPC	16-11	097	RCL9	36 09
016	x	-35	057	SPC	16-11	098	RCL1	36 01
017	ST0C	35 13	058	PREG	16-13	099	+	-55
018	RTN	24	059	SPC	16-11	100	ST09	35 09
019	*LBLA	21 11	060	SPC	16-11	101	CF0	16 22 00
020	SF0	16 21 00	061	*LBL1	21 01	102	GT05	22 05
021	RCL9	36 09	062	RCL3	36 03	103	*LBL4	21 04
022	RCL1	36 01	063	RCL8	36 08	104	SF0	16 21 00
023	+	-55	064	X=Y?	16-33	105	RCL8	36 08
024	ST09	35 09	065	GT02	22 02	106	RCL2	36 02
025	RCLC	36 15	066	RCLB	36 12	107	+	-55
026	ST08	35 08	067	1	01	108	ST08	35 08
027	GT0e	22 16 15	068	-	-45	109	*LBL5	21 05
028	*LBLC	21 15	069	RCLA	36 11	110	1	01
029	CF0	16 22 00	070	x	-35	111	RCL8	36 08
030	RCL8	36 08	071	RCLC	36 13	112	+	-55
031	RCL2	36 02	072	=	-24	113	RCL7	36 07
032	+	-55	073	RCLB	36 12	114	=	-24
033	ST08	35 08	074	+	-55	115	ST0B	35 12
034	RCL1	36 46	075	LN	32	116	1	01
035	ST09	35 09	076	RCLB	36 12	117	RCL9	36 09
036	*LBLc	21 16 15	077	LN	32	118	-	-45
037	1	01	078	=	-24	119	RCL0	36 00
038	RCL3	36 03	079	1	01	120	x	-35
039	+	-55	080	-	-45	121	ST0A	35 11
040	ST07	35 07	081	GT03	22 03	122	GT01	22 01
041	1	01	082	*LBL2	21 02	123	R/S	51

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