FINAL REPORT

DETERMINATION OF RAINFALL LOSSES IN VIRGINIA, PHASE II

by

James Cruise
Graduate Assistant

and

Shaw L. Yu
Faculty Research Engineer

(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

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SUMMARY

A procedure is presented by which regional unit hydrograph and loss rate parameters are estimated for the generation of design storm hydrographs for watershed in Virginia. The state is divided into seven hydrological regions, and unit hydrograph and loss rate parameters are computed for each region and then related to watershed characteristics such as drainage area, channel slope, etc. The Corps of Engineers's HEC-1 computer program was used to obtain optimal estimates of the Clark unit hydrograph and the standardized exponential loss rate function parameters. A total of 28 test watersheds and more than 160 storm events with corresponding streamflow data were analyzed. Parameter selection curves were developed with the results of the HEC-1 analyses.

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INTRODUCTION

In the design of highway systems a proper hydrologic analysis is necessary to ensure that adequate drainage control is maintained with respect to the design of culverts, channels, and other drainage facilities. Otherwise, the cost of maintaining and repairing highway sections subject to frequent flooding can be prohibitive. There is also a very real danger to human life when flooding results in the destruction of a culvert or bridge over a channel section. Thus, to ensure that drainage structures are properly designed it is extremely important that current and professionally acceptable hydrologic practices be employed by highway engineers.

There are basically two approaches to the design of hydraulic structures such as channels, culverts, bridges, etc. The first is a statistical approach wherein an analysis of the past hydrologic records of the watershed under consideration is utilized to predict flood peaks. This method is reliable and may be preferable in cases where there is a streamflow gage with a relatively long period of record. The second approach involves the application of a rainfall-runoff model that can be used where a gage and records are not available. The research reported here focused on one aspect of this latter approach.

A rainfall-runoff model is a mathematical formulation for deriving precipitation excess from a rainfall event and then converting that excess, or direct runoff, into a streamflow hydrograph. The component parts of this process, namely the derivation of the precipitation excess and its conversion to a runoff hydrograph – given the specific methodology to be applied – were the objects of concern in this investigation.

The methodology was tailored to fit a type of analysis currently in use by the Location and Design Division Section of the Virginia Department of Highways and Transportation. The results presented in this report should aid engineers responsible for the design of drainage control structures to make informed decisions.

PURPOSE AND SCOPE

The purpose of this investigation was to derive and regionalize the parameters necessary for the application of a rainfall-runoff model developed by the Corps of Engineers to watersheds in Virginia. This computer program is one of the primary vehicles by which rainfall-runoff analysis is performed by the Department of Highways and Transportation. This program, called HEC-1, and the specifics of its application by the Department's engineers have been described in a report by Burke (1980). With the "regionalized" parameters, it is expected that a highway engineer will be able to accurately estimate the storm runoff from a given design event when using the HEC-1 model.

Major work elements in this study included the

1. delineation of hydrologic regions in Virginia;
2. selection of the test watersheds; and
3. development of regionalized parameters.

In Phase I of the investigation, several watersheds were selected and some rainfall and streamflow data were obtained for testing the "regionalization" procedure (Burke 1980). In the present report, the following information is presented:

1. A brief description of the HEC-1 methodology and its application.
2. Results of the delineation of the state into hydrologically similar physiographic regions.
3. The collection and organization of the HEC-1 input data.
4. Results of the HEC-1 parameter optimization for each physiographic region.

HEC-1 Methodology and Application

The HEC-1 flood hydrograph package (Corps of Engineers 1973) is a general purpose rainfall-runoff event simulation model consisting of a main program and six subroutines. Two of the subroutines determine the optimal unit hydrograph, loss rate, or streamflow routing parameters by matching recorded and simulated hydrograph values. The other subroutines perform snowmelt, unit hydrograph, hydrograph routing and combining, and hydrograph balancing computations. Presently HEC-1 is one of the most widely used event simulation models for determining runoff from a given storm event.

In order to apply HEC-1 (or any unit hydrograph procedure) to a given watershed, certain parameters must be supplied. These include loss rate factors and unit hydrograph parameters, so that the program can obtain the precipitation excess. The loss rate for the HEC-1 model is an exponential decay function that depends on the rainfall intensity and the antecedent losses as illustrated below.

$$ALOSS = (AK + DLTK)(RAIN)^{ERAIN},$$

where

ALOSS = loss rate in inches per hour,

AK = basin loss coefficient,

DLTK = incremental loss coefficient,

RAIN = rainfall in inches per hour,

ERAIN = exponent of the rainfall relative to how storms occur over subarea;

and

$$AK = STRKR/(RTIOL)^{.1CUML},$$

in which

STRKR = basin loss index for start of storm in inches per hour,

RTIOL = ratio of loss coefficient (AK) to that AK after 10 inches or more of accumulated loss occurs, and

CUML = accumulated loss in inches.

Also

$$DLTK = .2\ DLTKR[1-(CUML/DLTKR)]^2$$
for (CUML/DLTKR)<1; otherwise zero;

and

DLTKR = amount of accumulated rain loss during which the loss coefficient is initially increased.

Clark's method is used for unit hydrograph computations. Table 1 lists the appropriate loss rate and unit hydrograph parameters determined regionally and gives short descriptions of their physical significance.

Table 1

HEC-1 Parameters

Storm Parameters

ERAIN – Exponent of the rainfall relative to how storms occur over the subarea. Varies between zero and 1.0.

Basin Parameters

STRKR – Basin loss index for start of storm. Depends upon basin characteristics such as soil type, land use, and vegetative cover.

RTIOL – Ratio of loss coefficient (AK) to that AK after 10 inches or more of accumulated loss. It's a function of the ability of the basin to absorb precipitation.

T_c – Time of concentration. Depends upon basin size and shape, length of channel, land cover, etc.

R -- Clark's storage constant. Can be taken as a fraction of TC.

Soil Moisture Parameter

DLTKR – Amount of accumulated rain loss during which the loss coefficient is initially increased. Depends primarily upon antecedent soil moisture deficit.

In watersheds where continuous recorder gages are present unit hydrograph and loss rate characteristics can be derived directly from observed storm events. However, in areas where no gages are available, which is the case for most areas, a synthetic unit hydrograph technique must be employed. There are several such procedures described in the literature, the most popular being Snyder's technique, which is mainly applicable to rural areas, and the Soil Conservation Service method, which is generally applied to urban watersheds. These synthetic hydrographs, together with some type of loss rate information, are then used in conjunction with rainfall frequency data to generate design hydrographs. The parameters of the selected unit hydrograph technique, the loss rate characteristics of the watershed under investigation, and the rainfall amount and distribution for the selected recurrence interval and duration is fed into HEC-1 and the program calculates the rainfall excess and generates the appropriate runoff hydrograph. Normally in design situations, some conservative estimate is made of the infilatration capacity of the soil, assuming already saturated conditions. For example, typical values of initial losses and infiltration rates in these cases would be about 1.0 in. and 0.10 in. respectively for a 10-year design storm.

It was the purpose of this research to derive unit hydrograph and loss rate characteristics which would be generally applicable to regions of the state in order to facilitate the computation of design hydrographs. To accomplish this, the state was divided into a number of hydrologically and physiographically similar regions. Three or four small gaged sub-basins were then chosen throughout these regions and a "reverse" procedure to the one described above was performed. In this case the program was used to derive the "optimal" unit hydrographs and loss rate parameters which would best reproduce the observed discharge hydrographs from the given rainfall hyetographs. A number of such events were analyzed for each test watershed. This procedure assumes the controversial principle that there exists only one proper unit hydrograph for any watershed. However, the range in the calculated values is also given in the results so that this principle need not necessarily be adhered to.

After the calculation of unit hydrograph and loss rate parameters for three or four sub-basins in each region, a relationship between these factors and the topographic characteristics of the watersheds in the region was determined. The topo characteristics used were drainage area, length, length to centroid, and average slope of the main channel. These characteristics have a long history of use in situations where the use of synthetic rainfall-runoff methods are necessary. The results of this analysis are given in the form of selection curves of the particular parameter of interest versus the appropriate basin characteristic for each region. The curve of best fit through the average values, as well as envelop curves which contain approximately 90% of the observed data, was obtained from the optimization procedure.

DELINEATION OF STATE INTO HYDROLOGIC REGIONS AND SELECTION OF SUB-BASINS

As is the case with most of the states of the middle-Atlantic region of the United States, Virginia can be divided into three distinct physiographic areas. Namely, the mountain, piedmont, and coastal plains. In addition, within the mountain section, the state has a Ridge and Valley area which consists mainly of the Shenandoah Valley. This region runs southwesterly from the northwest corner of the state, eventually running out into the Roanoke valley in the southwest mountains, as shown in Figure 1.

The state contains, in part or total, eight major river basins: the Potomac, James, Rappahannock, Roanoke, Chowan, Tennessee, York, and New. In addition, there are a few small coastal swamps on the eastern seaboard. Figure 2 shows the major river basins.

The state was first divided into eleven hydrologic regions based upon soils, topography, and major drainage basin, as shown in Figure 3. The labeling scheme for these regions was made by using first a letter indicating the physiographic region and then a number or numbers indicating the river basin or basins included in the region. Reference is made to Figures 1 and 2. For example, Region M2 includes the portion of James River Basin within the mountain region, and Region C25 includes the portions of James River basin and Chowan and Dismal Swamp basin within the coastal region, etc.

As shown by the figure, the integrity of the physiographic region as well as the major river basins in the state was maintained. However, it was later felt that some of the smaller watersheds could safely be combined with one of the larger basins. Some of the regions were, in fact, combined to form a single region when the results permitted such a change.

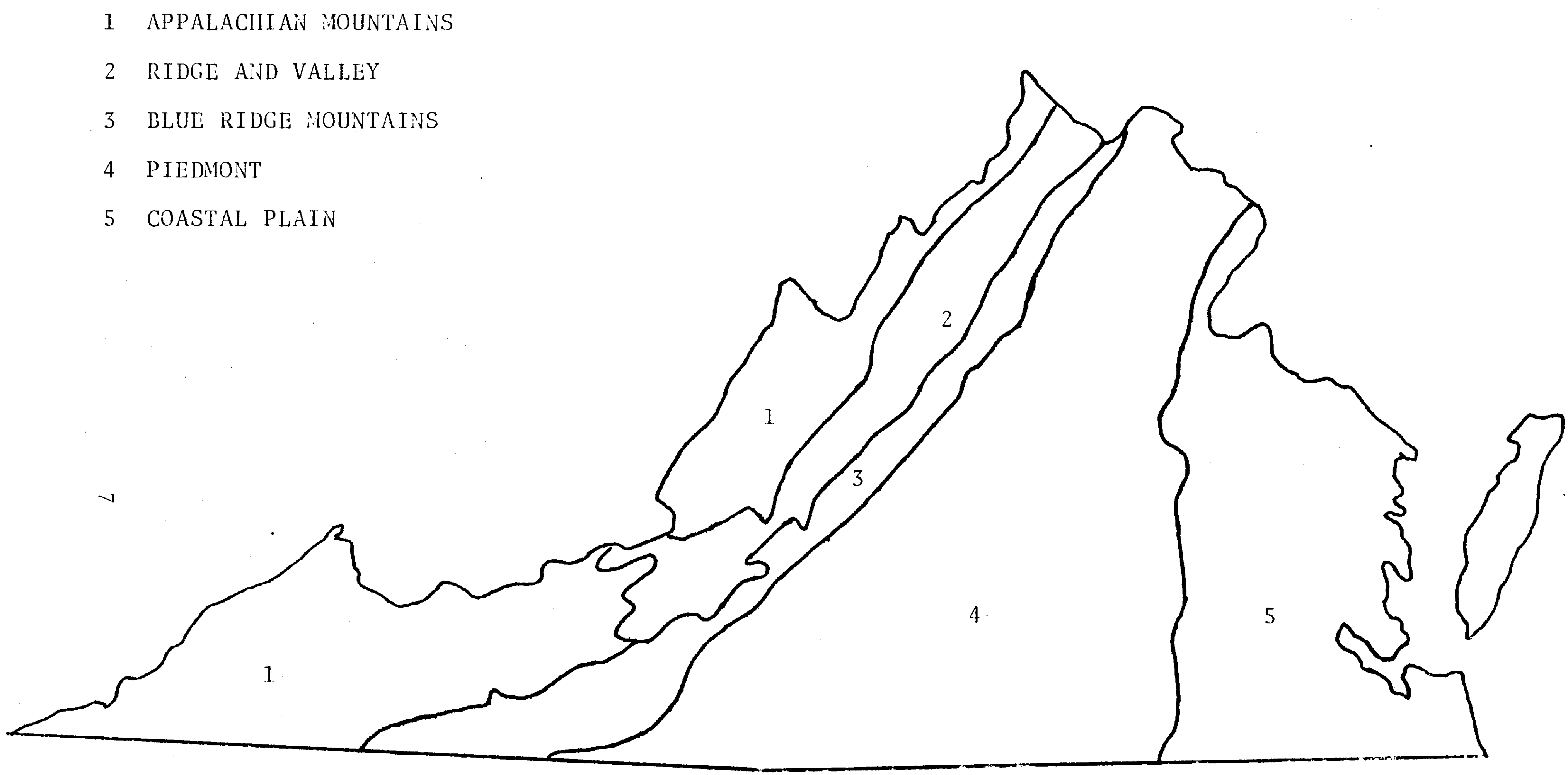

Figure 1. Physiographic regions of Virginia.

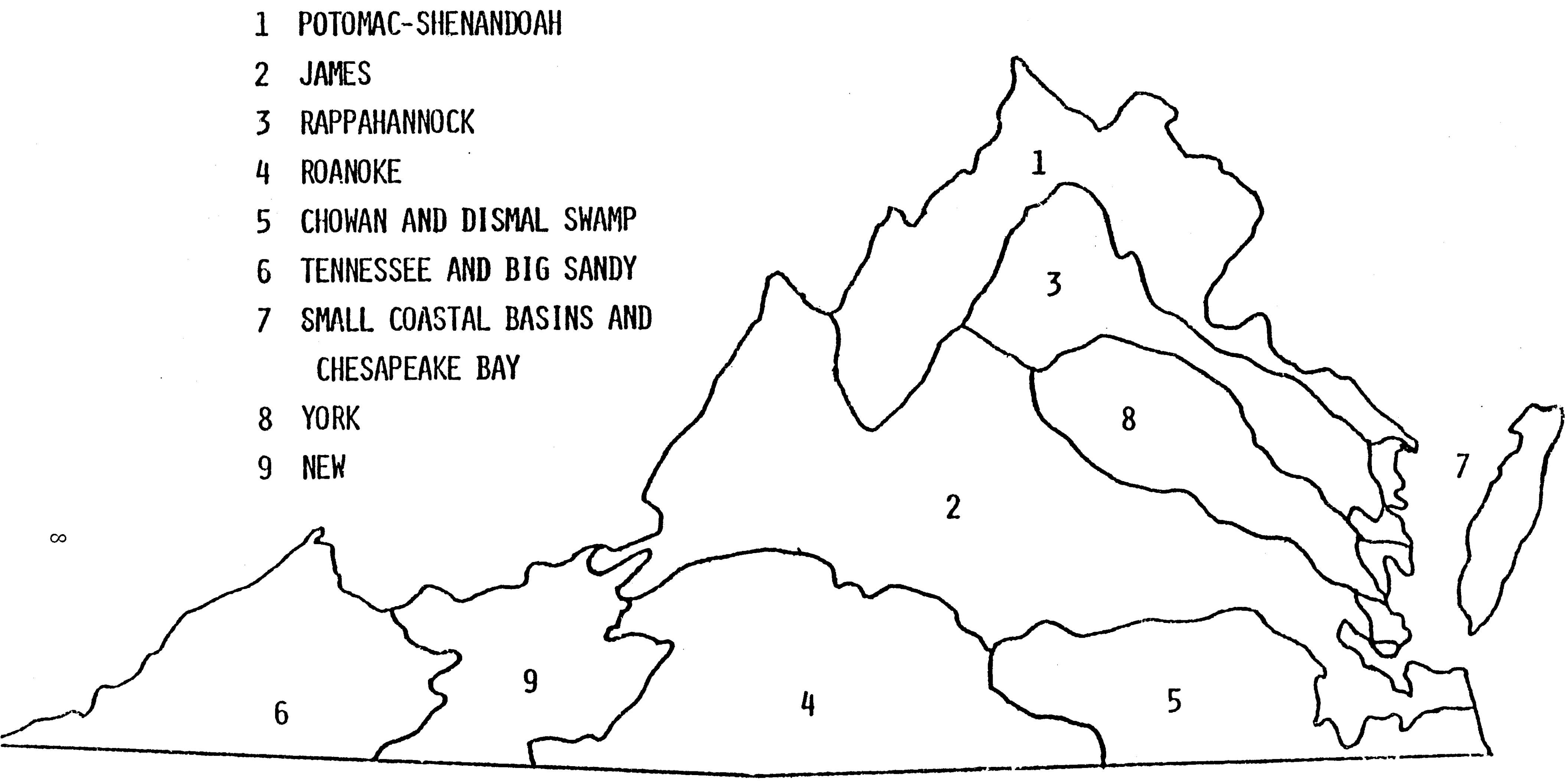

Figure 2. River basins in Virginia.

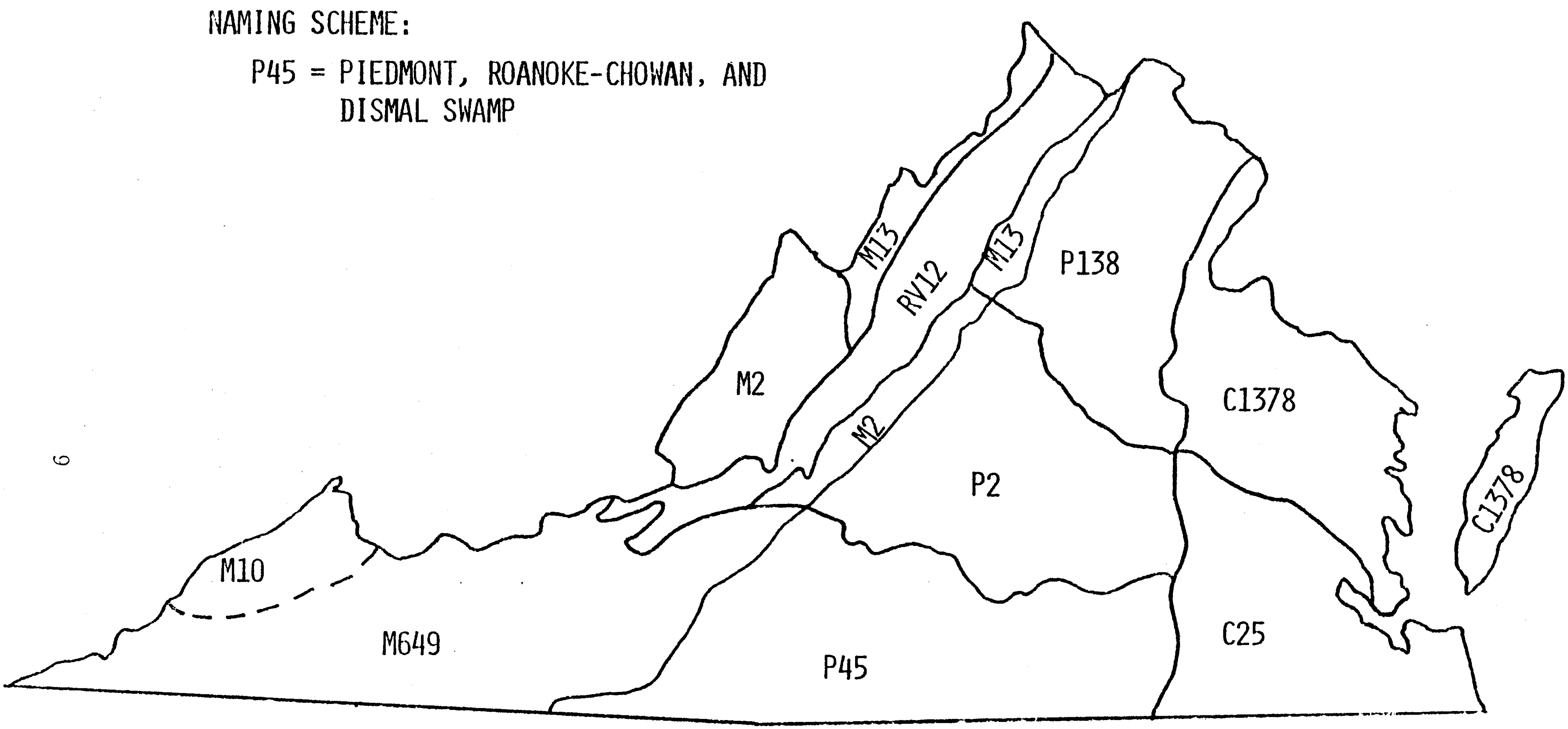

Figure 3. Preliminary HEC-1 Hydrologic regions in Virginia.

As mentioned earlier, at least three sub-basins were chosen for the HEC-1 analysis within each region. In the selection of these sub-basins, consideration was given to their relative size and their location within the region. An attempt was made to obtain sub-basins which varied enough in size so that a well-defined curve would result when the loss rate and unit graph parameters were plotted against basin characteristics. Also, sub-basins were selected so that as much of the total geographical area of each region as possible would be covered. Another consideration in this phase of the investigation was the amount of urban development in the watershed. Only sub-basins essentially rural in nature were analyzed. A list of these sub-basins and the topographic characteristics of each is given in Table 2.

DATA COLLECTION AND ORGANIZATION

The data needs of the HEC-1 loss rate optimization routine include hourly rainfall and hourly streamflow for selected candidate storms in the design watersheds (Burke 1980). Publications containing station histories for all rainfall and stream gage locations in Virginia were obtained from the U. S. Weather Bureau (1979) and the USGS (1967), respectively. While these publications were the best available, additional work was often required to locate stream gages and rain gages and the streamflow and rainfall data collected at these stations.

The collection and organization of the HEC-1 input data were a major portion of this project. Streamflow strip charts and rating tables for candidate storms were obtained from the USGS in Richmond. Streamflow records collected before approximately 1966 had to be obtained from the Federal Records Center in Suitland, Maryland, and this caused at least a two-week delay for each such request. Hourly rainfall data were obtained from the office of the State Climatologist in the Department of Environmental Sciences at the University of Virginia. These rainfall data were in the form of computer printouts or microfiche. USGS 1:24000 topographic maps were obtained for each design watershed, and these were examined for land use information and to determine if any significant impoundments existed upstream from the design watershed stream gage. Where such impoundments were discovered, the watershed was not analyzed.

Table 2

Test Watersheds by Region and their Basin Characteristics

Basin	D.A., mi^2	($km.^2$)	L, ft., (km.)	L_{ca} ft., (km.)	S_{st}, ft./ft.,	$\frac{LL_{ca}}{\sqrt{S_{st}}}$, $mi.^2$	(km/m)
Region P138							
Broad Run	50.5	(130.8)	99,500(30.33)	46,750(14.23)	0.0032	1.129	(3.45)
Battle Creek	27.6	(71.5)	60,250(18.36)	29,500(8.99)	0.0038	0.757	(2.37)
Rush River	14.7	(38.1)	---	---	---	---	---
Bunch Creek	4.37	(11.3)	22,875(6.97)	12,375(3.77)	0.0051	0.39	(1.18)
Colvin Run	5.09	(13.2)	---	---	---	---	---
Scott Run	4.69	(12.1)	---	---	---	---	---
Region P2							
Hardware River	119.0	(308.2)	106,000(32.31)	64,000(19.51)	0.0042	1.10	(3.37)
Holiday Creek	8.53	(22.1)	29,000(8.84)	10,000(3.05)	0.0094	0.29	(.88)
Falling Creek	32.80	(84.9)	74,962(22.85)	30,812(9.39)	0.00169	1.26	(3.85)
Bunch Creek	4.37	(11.3)	22,875(6.97)	12,375(3.77)	0.0051	0.39	(1.18)
Region P45							
Great Creek	30.7	(79.5)	66,750(20.34)	36,375(11.09)	0.00264	1.023	(3.13)
Allen Creek	53.4	(138.3)	95,875(29.22)	57,625(17.56)	0.00182	1.504	(4.82)
Georges Creek	9.24	(23.9)	37,625(11.47)	23,250(7.09)	0.0055	0.52	(1.59)
Region RV12							
Kerrs Creek	35.0	(90.6)	54,000(16.46)	32,625(9.94)	0.0096	0.49	(1.49)
Catawba Creek	34.3	(88.8)	103,875(31.66)	44,375(13.52)	0.00586	0.83	(2.54)
Opequon Creek	57.4	(148.6)	---	---	---	---	---
Abrams	16.50	(42.7)	55,750(16.99)	38,625(11.77)	0.0063	0.64	(1.95)
Region M2							
Rockfish River	94.6	(245.0)	75,909(23.14)	30,159(9.19)	0.0033	0.90	(2.75)
Piney River	47.6	(123.3)	91,875(28.00)	52,500(16.00)	0.0165	0.50	(1.54)
North River	17.2	(44.5)	52,250(15.93)	26,750(8.15)	0.0235	0.29	(.89)
Region M649							
Chestnut Creek	39.0	(101.0)	72,875(22.21)	35,000(10.67)	0.0040	0.88	(2.69)
Tinker Creek	11.7	(30.3)	24,000(7.31)	12,625(3.85)	0.009	0.30	(.91)
SF Holston River	76.1	(197.1)	110,625(33.72)	63,250(19.28)	0.00565	0.96	(2.94)
Region M6							
Cranes Nest River	66.5	(172.2)	95,000(28.96)	59,500(18.14)	0.0059	0.88	(2.69)
Regions C1378 and C25							
Hoskins Creek	15.4	(39.9)	44,125(13.45)	20,625(6.29)	0.00197	0.88	(2.69)
Dragon Swamp	84.9	(219.9)	106,750(32.54)	46,500(14.17)	0.0094	2.13	(6.49)
Totopotomoy Creek	26.6	(68.9)	70,687(21.55)	38,000(11.58)	0.00202	1.204	(3.68)
Aquia Creek	34.9	(90.4)	74,750(22.78)	41,125(12.53)	0.00239	1.153	(3.53)
Giles Run	4.54	(11.7)	---	---	---	---	---

The physical characteristics of each test watershed were obtained from USGS surface water data reports or from topographic maps.

RESULTS OF HEC-1 OPTIMIZATION

The map in Figure 4 shows the final configuration of the hydrologic regions of the state. As can be seen, the original Region M13 has been combined with Region P138 and the old Region M1 has been likewise combined with Region M2. Regions C1378 and C25 have been combined as well. In all cases, insufficient data were available for appropriate analysis in the deleted region, which made it impossible to define parameter selection curves for that region. Also, in some cases the parameter selection curves derived for one region were very similar to those for another region. Therefore, the logical choice was to combine the two regions in each case.

A total of 28 watersheds were used in the HEC-1 analysis. The topographical characteristics of these watersheds were shown in Table 2. Although the basins ranged in size from 4.37 $mi.^2$ to 119 $mi.^2$, an attempt was made to restrict the analysis to basins of 100 $mi.^2$ or less. This was done because of the well known difficulties of conducting a unit hydrograph analysis on relatively large watersheds. On the other hand, it was necessary to select a range of basin sizes in order to properly define the parameter selection curves. Although an attempt was made to obtain complete areal coverage of each region, the criteria for basin selection mentioned above made this impossible in some cases.

In all, 160 storms were analyzed for the seven regions described above, which averages out to about 23 events per region. These storms were selected on the basis of criteria usually applicable to unit hydrograph studies. The results of this analysis are shown in Table 3. The values in this table are the averages obtained for each watershed by regional groupings. Brief discussions of these results are given in the following paragraphs.

<u>Region P138 - M13</u> – This region is the piedmont and mountain portions of the Potomac-Shenandoah, Rappahannock, and York River basins. Although a total of six basins were available in this region, only four were actually original to this study and were used in the entire analysis. The other two, Colvin Run and Scott Run, were both obtained from a previous study (Cruise 1977) and since they are both about the same size as

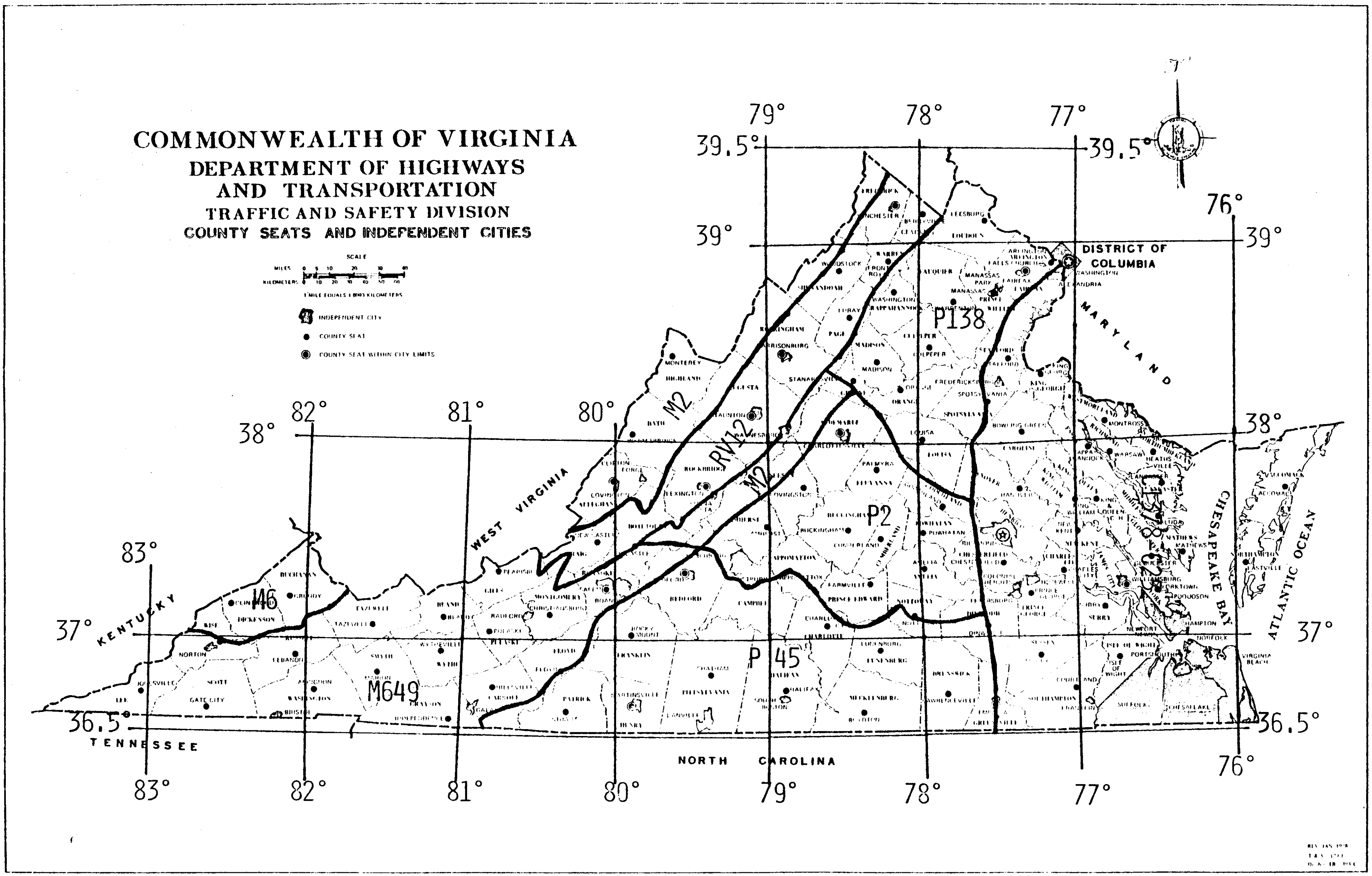

Figure 4. Final HEC-1 hydrologic regions in Virginia.

Table 3

Results of HEC-1 Optimization by Region

Basin	T_c (hr.)	R(hr.)	STRKR	ERAIN	DCTKR	RTIOL
			Region P138			
Broad Run	6.5	9.6	0.42	0.50	1.34	2.19
Battle Creek	4.7	4.2	0.35	0.50	1.28	2.47
Rush River	4.0	4.2	0.34	0.50	1.30	2.90
Bunch Creek	2.10	3.30	0.26	0.50	1.58	3.95
			Region P2			
Hardware River	15.9	9.16	0.44	0.50	1.85	2.28
Holiday Creek	3.9	4.71	0.24	0.50	1.42	3.41
Falling Creek	10.66	10.50	0.28	0.50	1.30	2.81
Bunch Creek	2.10	3.30	0.26	0.50	1.58	3.95
			Region P45			
Great Creek	14.30	5.80	0.38	0.50	1.73	2.90
Allen Creek	16.50	6.50	0.25	0.50	1.50	3.0
Georges Creek	7.9	1.80	0.34	0.50	1.85	3.81
			Region RV12			
Kerrs Creek	6.9	4.12	0.23	0.50	0.98	3.55
Catawba Creek	6.90	8.52	0.22	0.50	1.34	3.53
Opequon Creek	10.51	6.40	0.36	0.50	1.18	3.30
Abrams Creek	4.63	6.50	0.20	0.50	1.12	3.90
			Region M2			
Rockfish River	5.90	13.10	0.30	0.50	1.10	2.42
Piney River	4.50	7.71	0.20	0.50	1.43	3.25
North River	4.00	5.80	0.15	0.50	1.08	4.50
			Region M649			
Chestnut Creek	6.97	4.5	0.25	0.50	1.97	2.73
Tinker Creek	2.75	2.0	0.19	0.50	1.19	5.46
SF Holston River	14.0	9.8	0.29	0.50	1.21	2.50
			Region C1378-C25			
Hoskins Creek	7.6	19.2	0.30	0.50	0.74	2.25
Dragon Swamp	53.5	18.0	0.13	0.50	1.065	4.21
Tototomoy Creek	16.0	44.8	0.12	0.50	0.56*	1.86
Aquia Creek	6.5	11.7	0.24	0.50	0.97	3.00
Giles Run	2.65	1.9	0.27	0.30	1.03	3.25

*Not used in average because of urban development in basin.

Bunch Creek, one of the original form basins, they were used only to support the results from that basin.

An analysis of the results indicated that the parameters T_c, R, STRKR, and RTIOL varied systematically with basin factors, and thus parameter selection curves were developed in these cases. Of the other two parameters, experience has shown that ERAIN always averages about 0.50; thus this parameter was set at that value. The other parameter, DLTKR, showed no systematic variation and, in fact, varied relatively little from basin to basin. Therefore, an average, or region-wide, value of about 1.42 in. is recommended for this region.

The parameter selection curves for this region are shown in Figures A-1 through A-4 of the Appendix. In each of these figures, the line of best fit (solid line) is drawn through the average value of the parameter. The dashed line are envelope curves which contain approximately 90% of the observed data (these are not 90% confidence intervals). These curves are shown only as a means of indicating the scatter in the data for each parameter.

Region P2 -- This region contains the piedmont portion of the James River basin. As can be noted from Table 3, Bunch Creek near Boswell's Tavern was included in this region as well as the previous one. This was necessary because one of the original basins selected for this region had to be deleted, and since Bunch Creek is located in Region P138 but very close to the border with Region P2 it was decided to replace the deleted basin with Bunch Creek. For this region, a general value of 1.54 in. is recommended for DLTKR as well as 0.50 for ERAIN. The parameter selection curves for the other four parameters are shown in Figures A-5 through A-8.

Region P45 - This region contains the piedmont portion of the Roanoke and Chowan River basins. Three sub-basins were selected for analysis in the region. The results indicated that a region-wide value of DLTKR of about 1.69 in. would be appropriate, along with the usual value of 0.50 for ERAIN. The parameter selection curves for the other parameters are given in Figures A-9 through A-12.

Region RV12 - This region consists of the ridge and valley areas of the state which lie between the piedmont plateau and the western mountain. This area consists mainly of the Shenandoah Valley and its subsidiaries and contains portions of two river basins - the Potomac-Shenandoah and the James. Four sub-basins were utilized in the analysis of this area and a total of 26 storm events were analyzed. As usual, a region-wide value of 0.50 was set from ERAIN and a general value of about 1.17 in. is recommended for DLTKR. The parameter selection coves for the other parameters are shown in Figures A-13 through A-16.

Region M2-M1 - This region contains the mountainous portions of the Potomac-Shenandoah and the James River basins. Part of it lies west of the Shenandoah valley and a portion located east of the ridge and valley section. Because this region consists of a relatively small land area, only three appropriate gages from it were available for analysis and they do not effectively cover the entire area. A total of 22 events were analyzed and the parameter selection curves based on these results are shown in Figures A-17 through A-20. In addition, the data indicated a region-wide value for DLTKR of about 1.20 in. as well as the usual 0.50 for ERAIN. The hydrographs in this region consistently showed an unusual amount of storage present for such a steep terrain. This fact will be discussed later when a comparison of the results from the different regions is made.

Regions C1378 and C25

These regions contain the coastal portions of the Potomac, Rappahannock, James, Chowan, and York basins as well as some minor coastal streams. They were combined for this analysis because sufficient data could not be found in Region C25 to make the analysis feasible. Five sub-basins were chosen; however, all of them are located in Region C1378.

For this region a general value of DLTKR of 0.95 in. is recommended along with an ERAIN of 0.50. The parameter selection curves for the other parameters are given in Figures A-21 through A-24. As can be observed from the graphs, the values for Dragon Swamp did not assimilate well with the other data in the cases of the RTIOL and R parameters. The reason for this discrepancy may lie in the nature of the stream system and drainage basin for this region. The floodplain appears to be wide and swampy, and the entire drainage area has an extremely mild slope compared with that of the other basins in the region. This latter fact, combined with the very large drainage area of the test basin and the resulting long lengths, leads to a length/slope factor twice as large as those of any of the other basins in the region. Therefore, it appears that Dragon Swamp is sufficiently dissimilar from the other basins that its data should not be relied upon as heavily.

Region M649 -- This region is made up of the mountainous portions of the Tennessee, Roanoke, and New River basins. It consists basically of the southwestern mountains of the state. Three suitable gage locations were selected which, unfortunately, do not completely cover the region. The results indicated a general value of DLTKR of about 1.45 in. with an ERAIN of 0.50. The parameter selection curves for the other parameters are given in Figures A-25 through A-28.

Region M6 – Region M6 is a small area in the very southwestern corner of the state which falls in the Big Sandy River basin. Only one stream was analyzed in this region due to its very small size. The results from this gage compared fairly well with those from region M649, except for the RTIOL parameter, which fell outside of the 90% scatter limits for that region. Therefore, it is recommended that the parameter selection curves for region M649 be used for region M6 for the parameters STRKR, R, and Tc, and that an RTIOL value of 3.5 be applied together with a DLTKR value of 1.14 in. and an ERAIN of 0.50.

Comparison of Results

It was deemed advisable to make a comparison of the results from the different regions in order to ascertain the consistency of variation from region to region. To this end three watersheds varying in sizes from 9 to 50 $mi.^2$ were selected, and the unit hydrograph and loss rate parameters for each watershed were determined assuming that it lies within each of the seven regions. The results are shown in Table 4.

A careful review of Table 4 shows a few anomalies or inconsistencies in the data. First, the slope of the exponential portion of the loss rate curve (RTIOL) increases in both a southerly direction down the piedmont and a westerly direction into the mountains. One would expect an increase in RTIOL in the mountains due to the shallow soils and steep slopes; however, the reverse should be true for the southern piedmont. As can be noted from the table, in nearly every

Table 4

Regional Comparison of Parameters

Region	T_c	R	STRKR	DLTKR	RTIOL
Georges Creek					
P138	3.0	3.75	0.29	1.42	3.19
P2	4.1	4.5	0.24	1.54	3.40
P45	6.5	2.0	0.34	1.69	3.80
RV12	3.4	4.8	0.17	1.17	4.15
M2	3.90	8.0	0.14	1.20	5.20
M649	2.00	2.8	0.18	1.45	5.50
C1378-C25	5.00	*	0.29	0.95	3.10
Falling Creek					
P138	5.50	10.2	0.36	---	2.35
P2	9.9	10.5	0.28	---	2.80
P45	14.5	7.6	0.38	---	2.85
RV12	6.8	*	0.22	---	3.55
M2	4.3	*	0.18	---	3.70
M649	6.20	10.0	0.24	---	3.10
C1378-C25	16.9	36.0	0.24	---	2.30
Broad Run					
P138	6.5	9.6	0.42	---	2.20
P2	11.8	9.5	0.33	---	2.60
P45	16.2	7.4	0.40	---	2.55
RV12	9.8	*	0.27	---	3.40
M2	5.0	*	0.21	---	3.15
M649	9.0	8.9	0.26	---	2.75
C1378-C25	25.0	26.5	0.20	---	2.10

*Outside the range of data.

case region P45 has the largest value of RTIOL of any of the piedmont regions, notwithstanding the fact that it has the mildest average slope of the three. A preliminary evaluation of the soils of the piedmont region has indicated that they become deeper and a little better drained in the southern regions. However, the predominant soils in all three regions are classified as moderately permeable. Therefore, it would appear that, if anything, the RTIOL value should decrease slightly for the southern regions of the piedmont.

At this time there is no good explanation for this anomaly; however, it will receive further study and it is hoped that its cause can be ascertained. In any case, the increase is slight and it is not thought to be a serious problem at this time.

A second, more serious, anomaly exists with respect to the storage coefficients, or R values, in regions P45 and M2. As previously noted, the hydrographs in region M2 demonstrated an inordinate amount of storage for a mountainous region. Conversely, the sub-basin in region P45 did not exhibit the storage characteristics one would expect to find in a relatively mild piedmont area. This is borne out by an examination of the results in Table 4. In every case region M2 has the largest value (or it is completely off the scale) and region P45 has the smallest – the exact reverse of what one would expect given the fact that region P45 is the mildest of the six while region M2 is by far the steepest. Even though the last two cases are out of the range of the data from which the curve for region M2 was derived, a comparison of the curves for the seven regions (Figures A-1 through A-28) indicates that the curve for region M2 has a definite shift to the right while that for region P45 not only shifts to the left but has a curvature opposite that of the other five curves. At present, no satisfactory explanation for this anomaly has been discovered.

A slight anomaly exists in the starting loss values (DLTKR and STRKR) for the coastal zone. As can be observed from the table, these values are smaller than would be expected, given the characteristics of the region. The derived values are more in line with those for the piedmont regions, which have steeper slopes and firmer land surfaces. However, the long time of concentrations and high storage coefficients of the unit hydrographs in the region will probably offset and even in the loss rate function.

RECOMMENDATIONS

Based upon the information gathered for this investigation and the data resulting from the analyses, the following recommendations are made with respect to the seven regions included in the study.

1. It is recommended that the state of Virginia be divided into the seven hydrologic regions as illustrated in Figure 4.

2. Regional values of parameters ERAIN and DLTKR are recommended for use throughout the study area. The values given for each region in the previous section are averages for the watersheds utilized in each region. It might be advisable, therefore, to use more conservative values of DLTKR in the design situations.

3. Parameter selection curves (Figures A-1 through A-28) are recommended for use in selecting values of RTIOL, STRKR, Tc, and R. These curves accompany the discussion of each region in the previous section. The curves are based on a small sample of a very limited range of data and should not be extended outside this range. Unstable and inaccurate results are likely to be obtained if this is done. Since these curves are also based on average values in each case, it might also be advisable to use more conservative values in design situations. The envelope curves given on each figure should aid in this selection.

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APPENDIX

Parameter Selection Curves

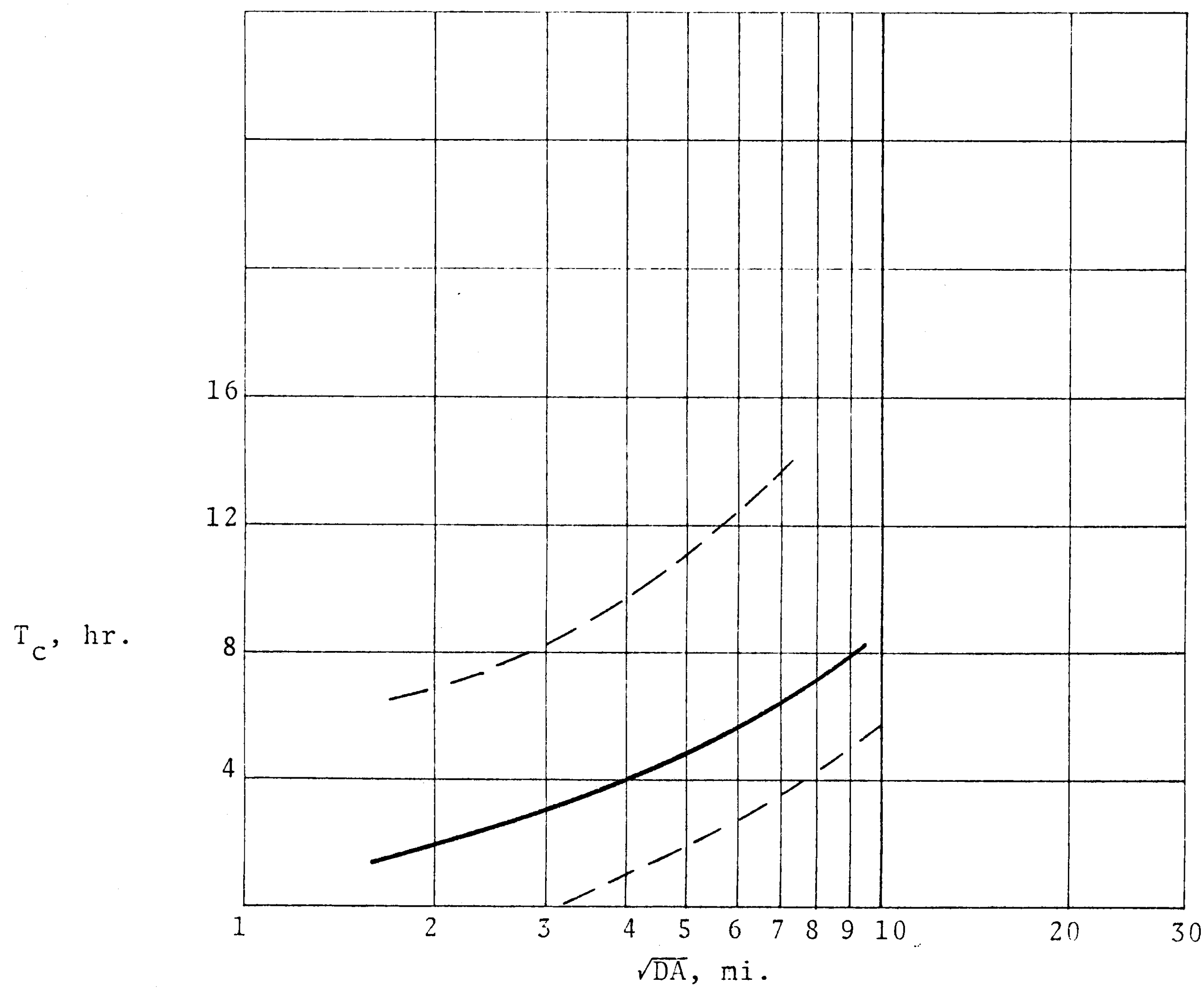

Figure A-1. Parameter selection curve, T_c for region P138-M13.

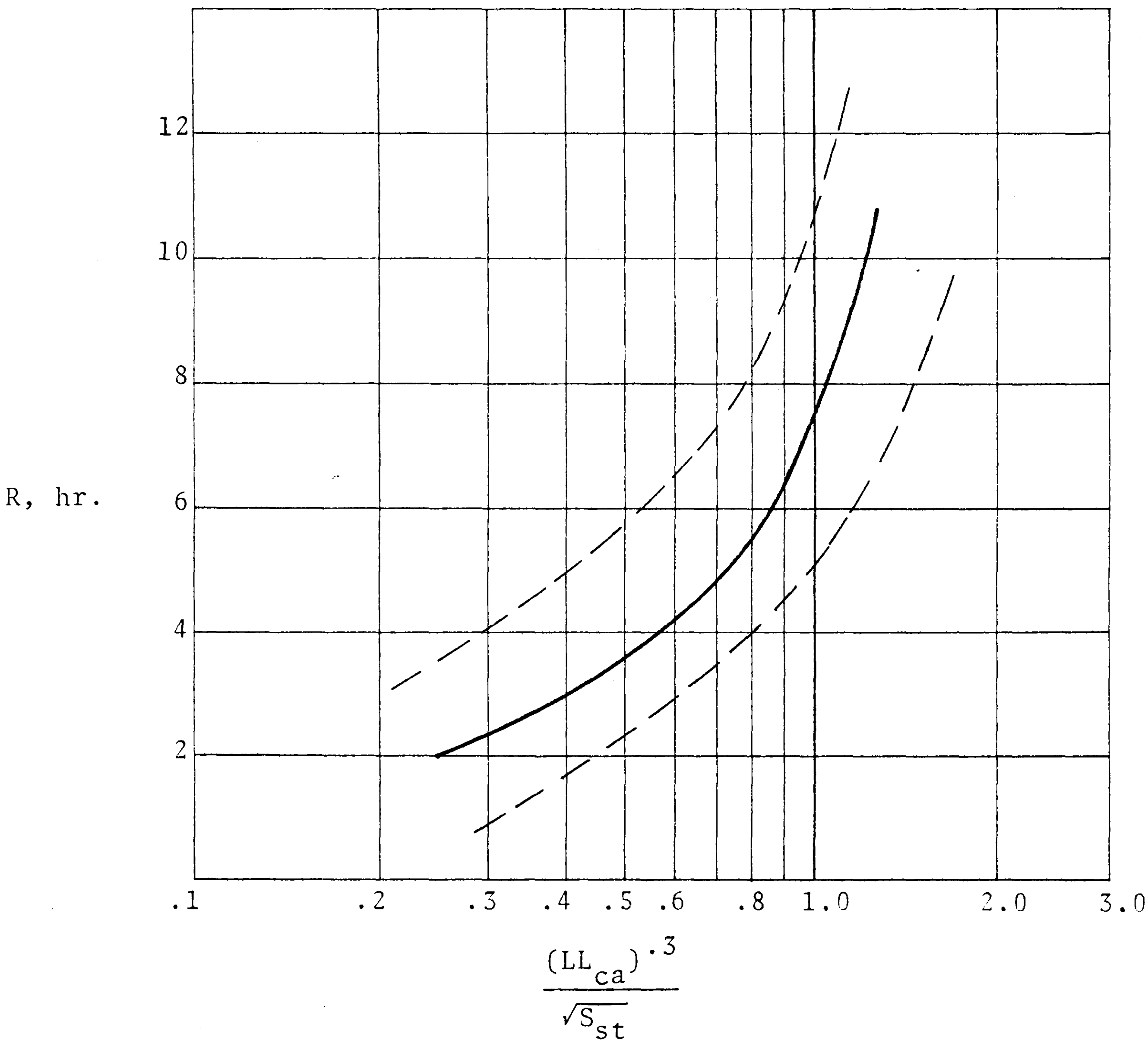

Figure A-2. Parameter selection curve, R for Region P138-M13.

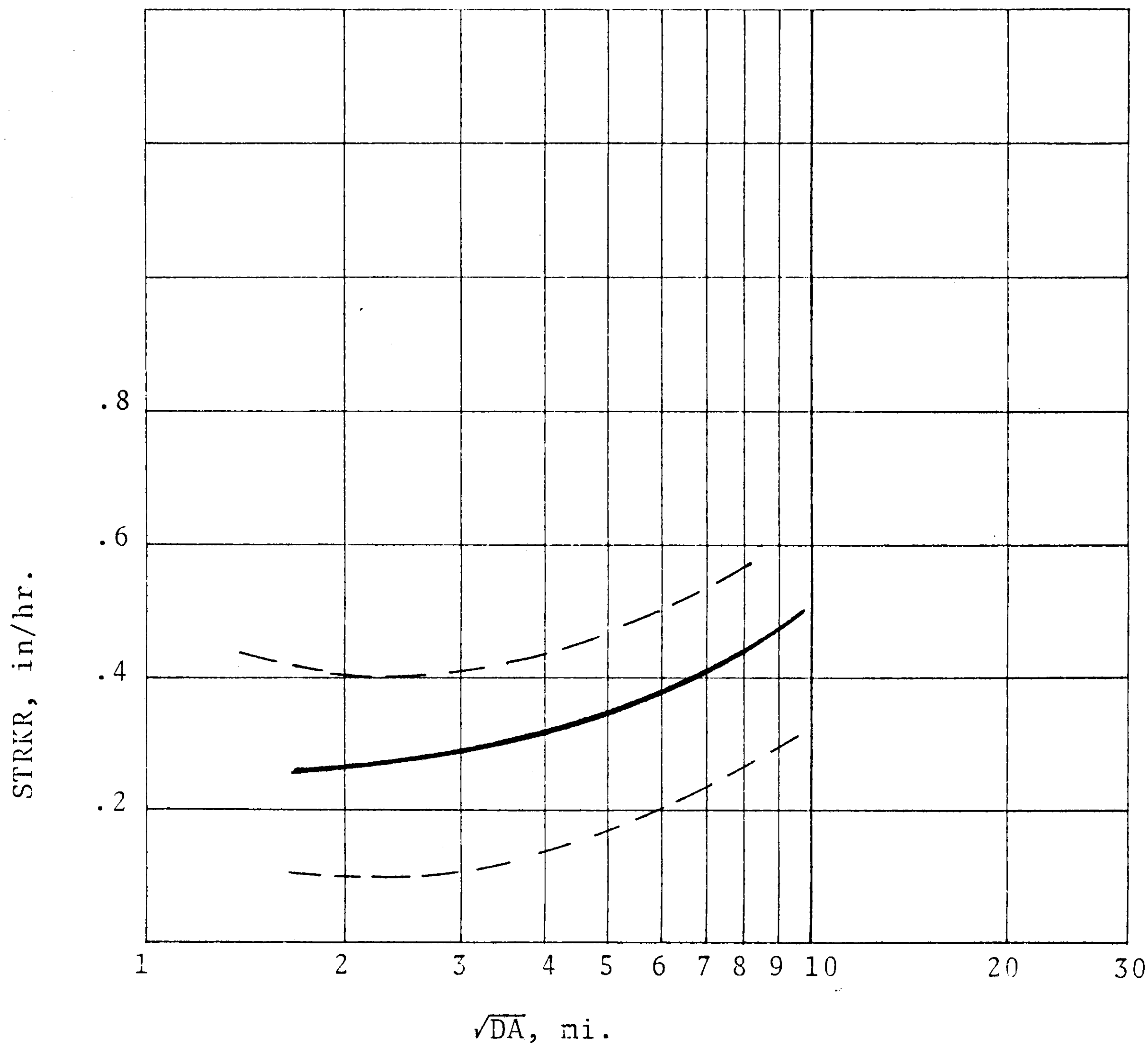

Figure A-3. Parameter selection curve, STRKR for Region P138-M13.

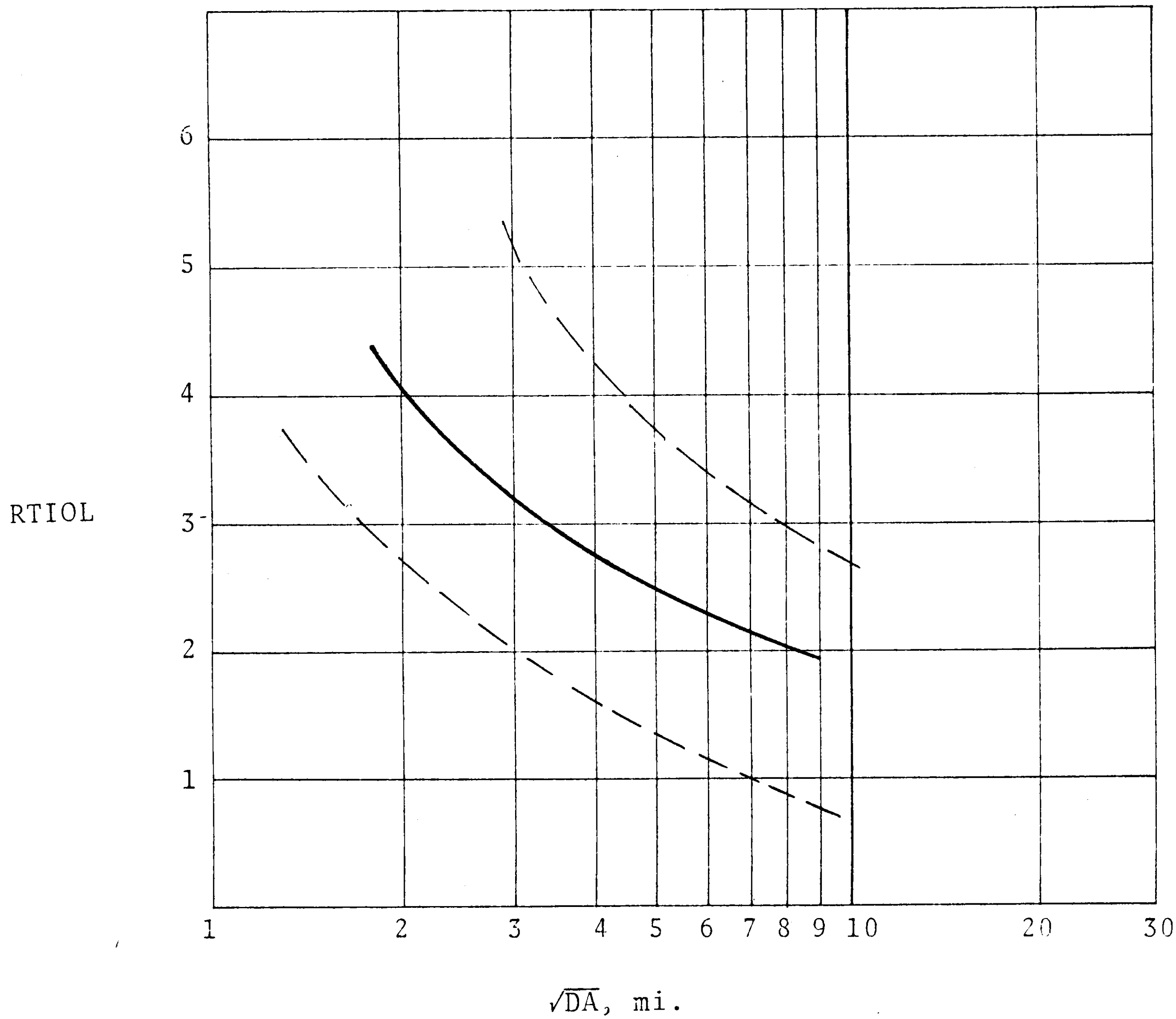

Figure A-4. Parameter selection curve, RTIOL for Region P138-M13.

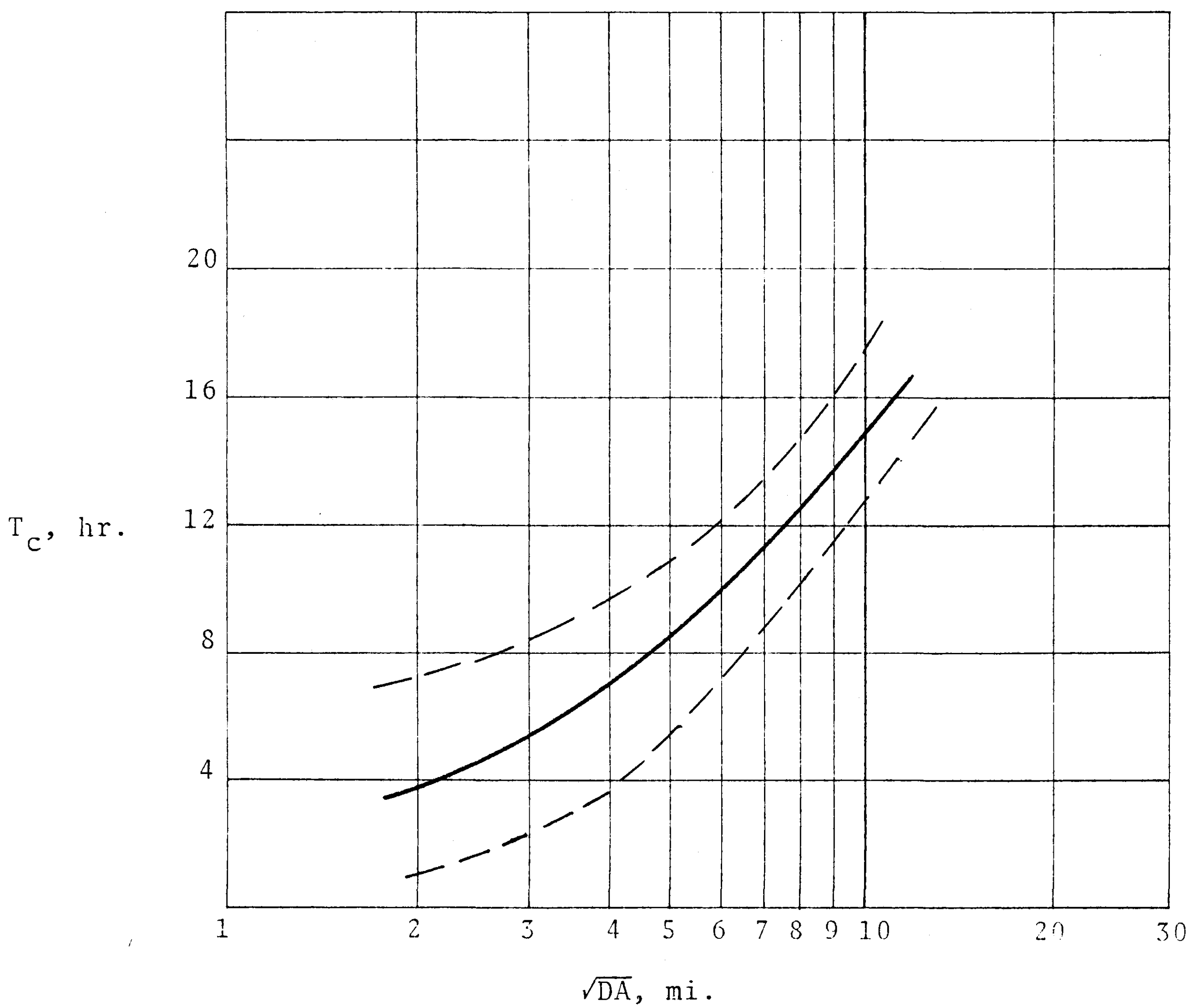

Figure A-5. Parameter selection curve, T_c for Region P2.

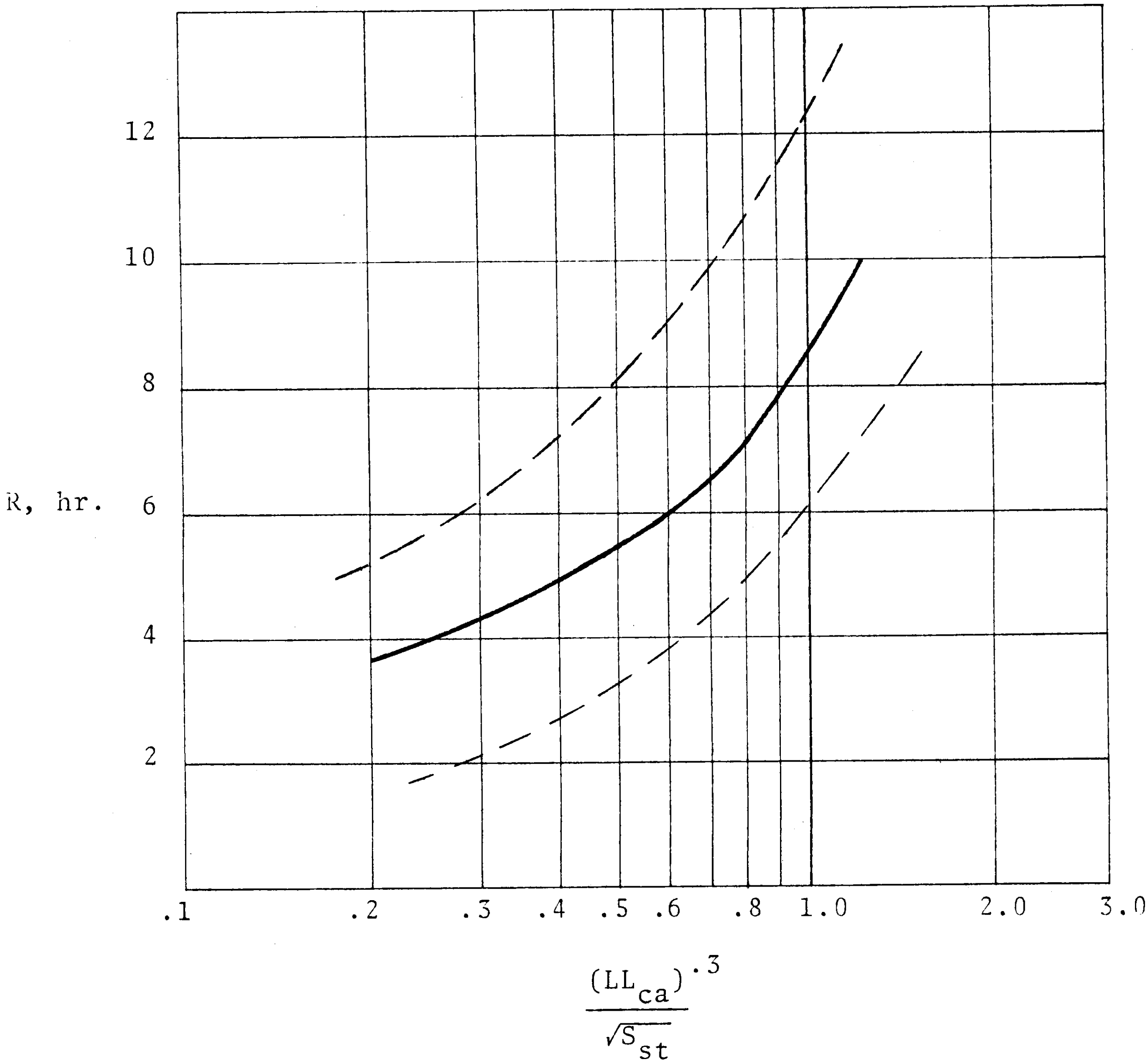

Figure A-6. Parameter selection curve, R for Region P2.

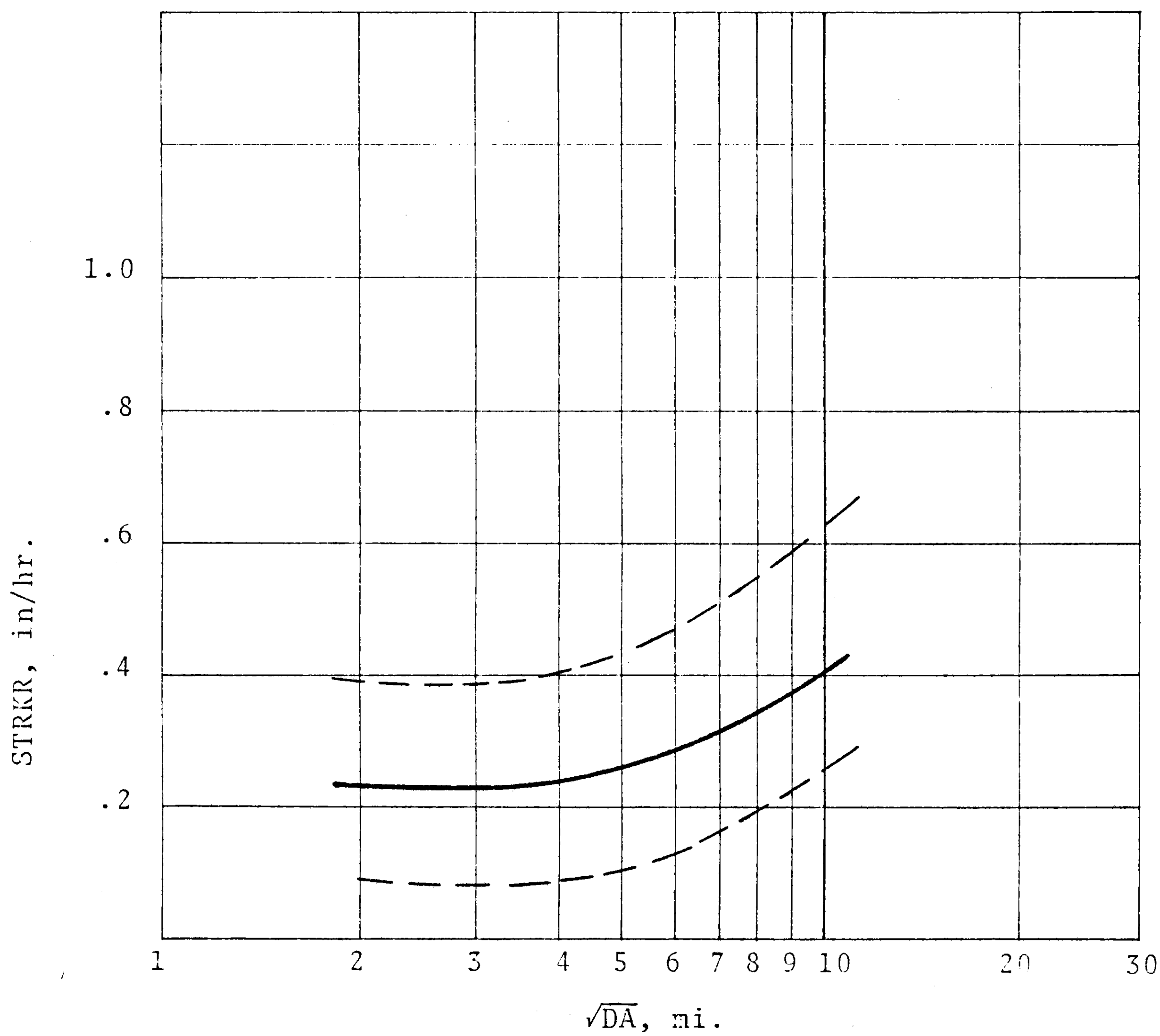

Figure A-7. Parameter selection curve, STRKR for Region P2.

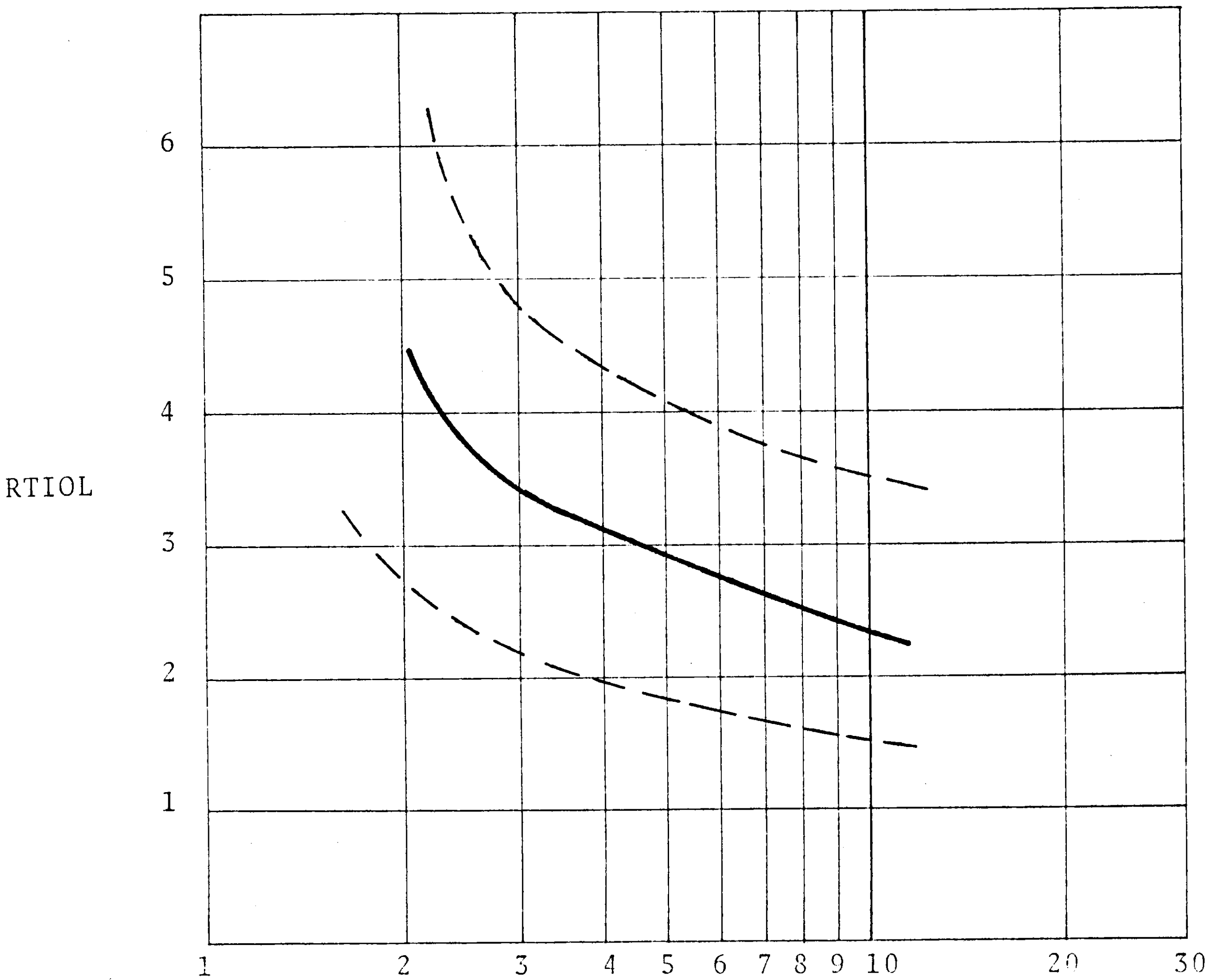

Figure A-8. Parameter selection curve, RTIOL for Region P2.

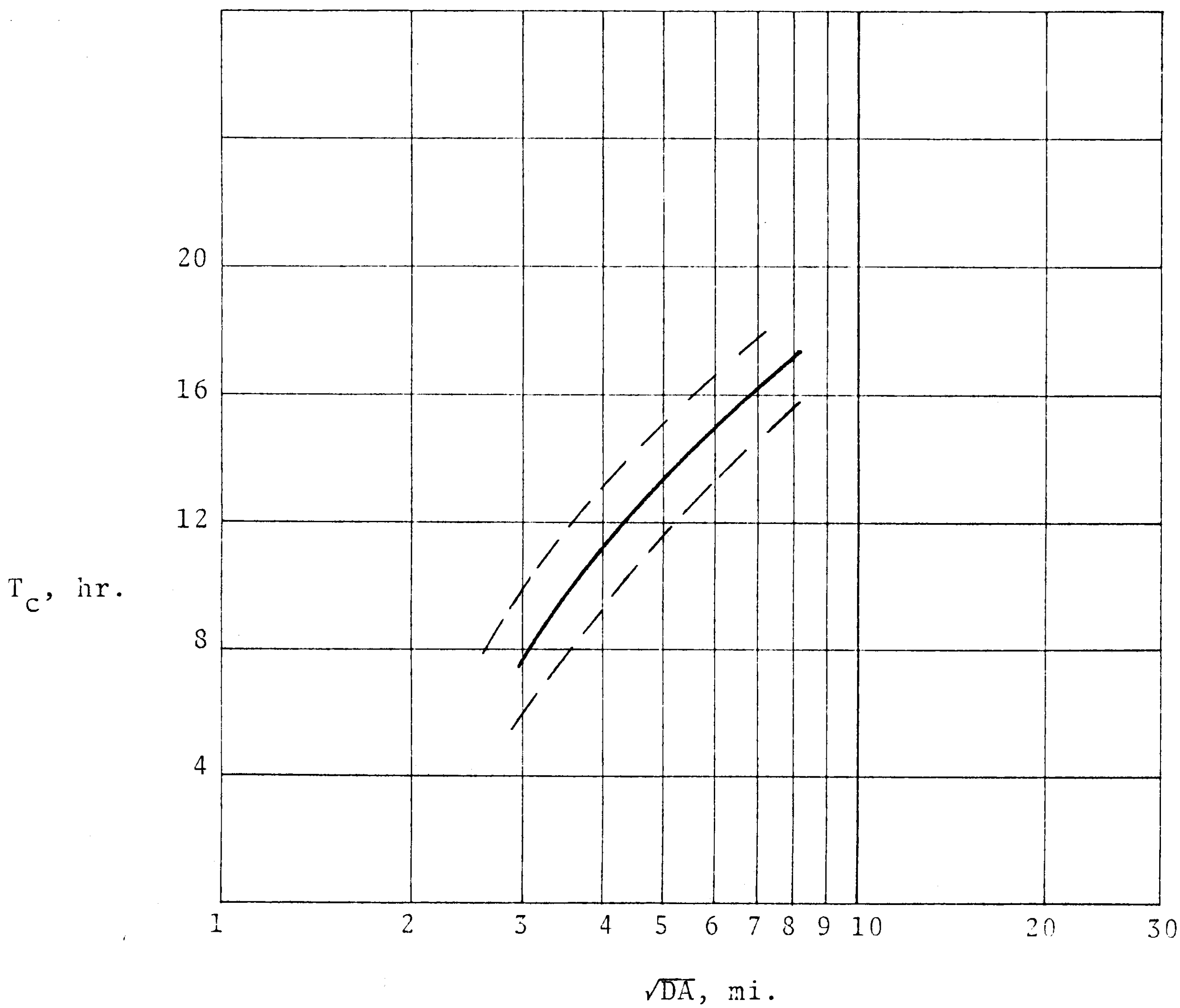

Figure A-9. Parameter selection curve, T_c for Region P45.

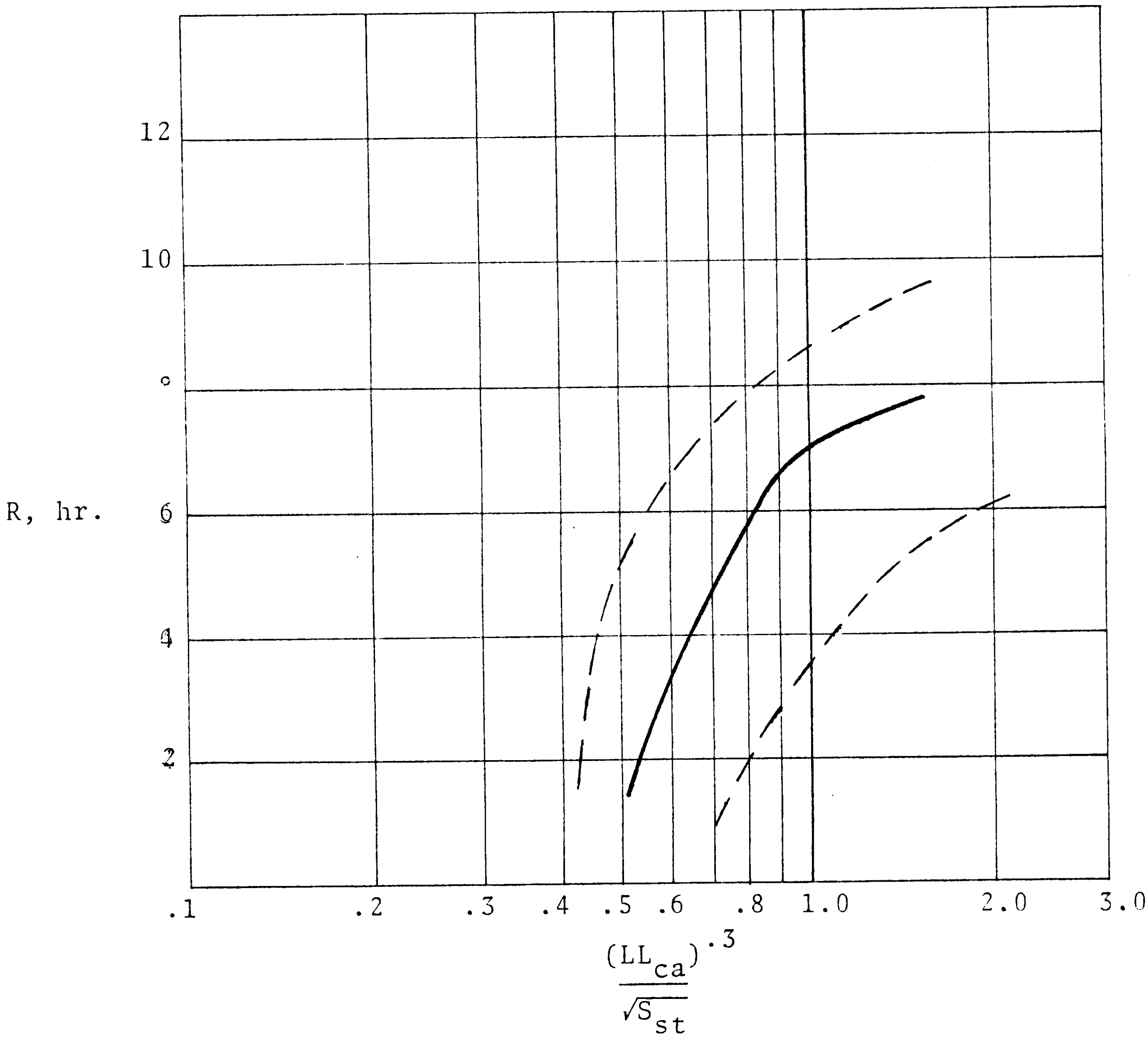

Figure A-10. Parameter selection curve, R for Region P45.

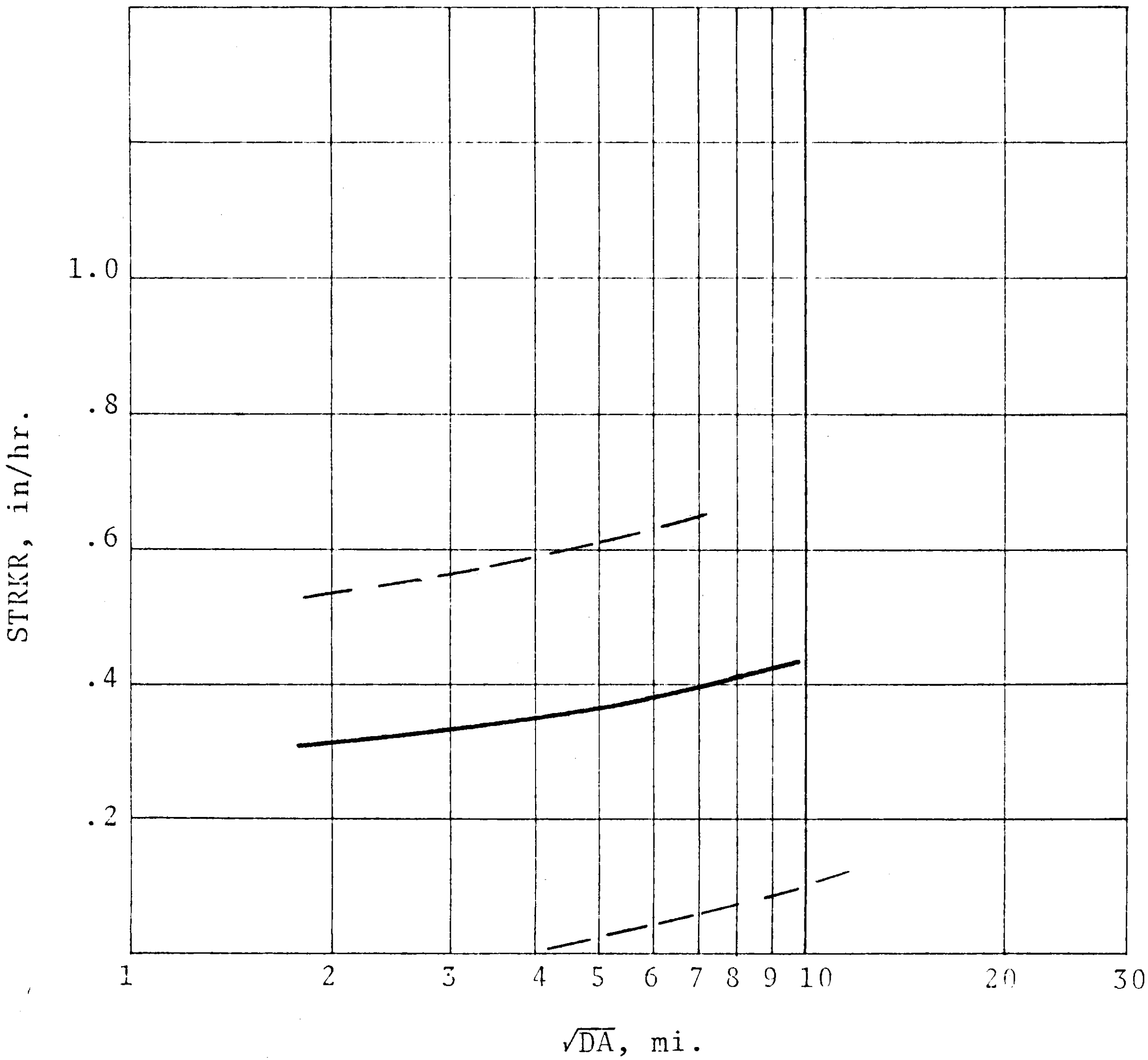

Figure A-11. Parameter selection curve, STRKR for Region P45.

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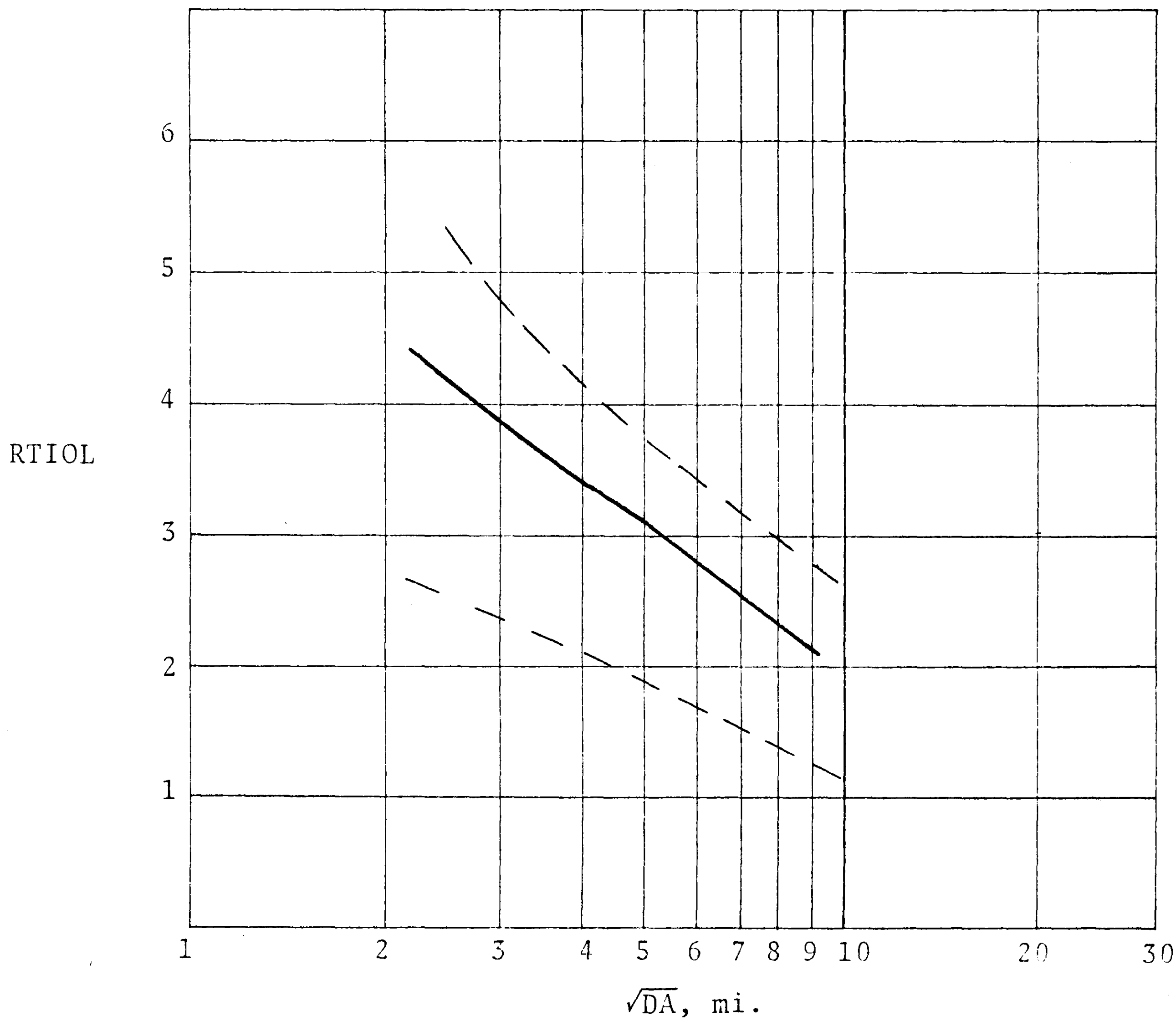


Figure A-12. Parameter selection curves, RTIOL for Region P45.

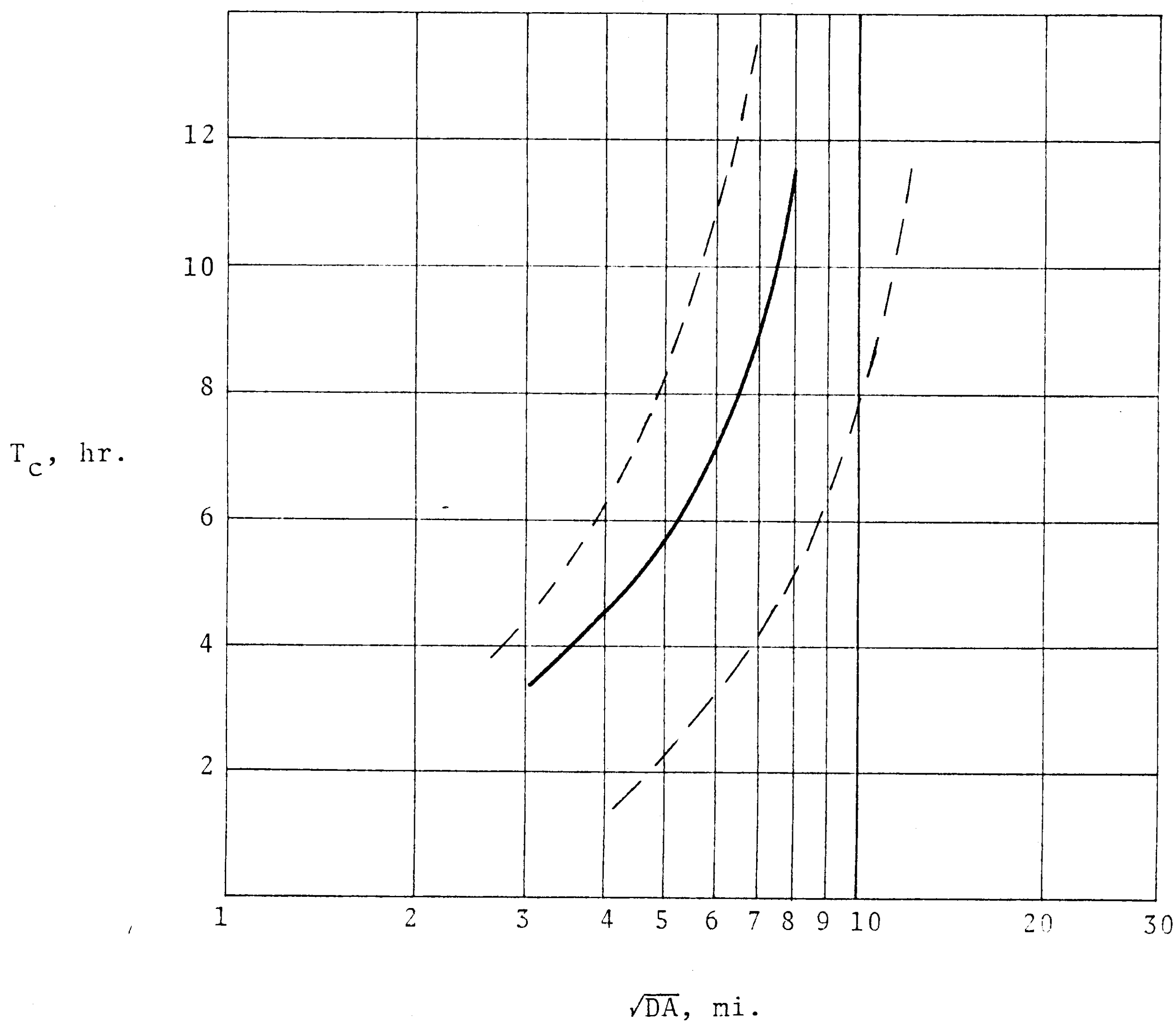


Figure A-13. Parameter selection curve, T_c for Region RV12.

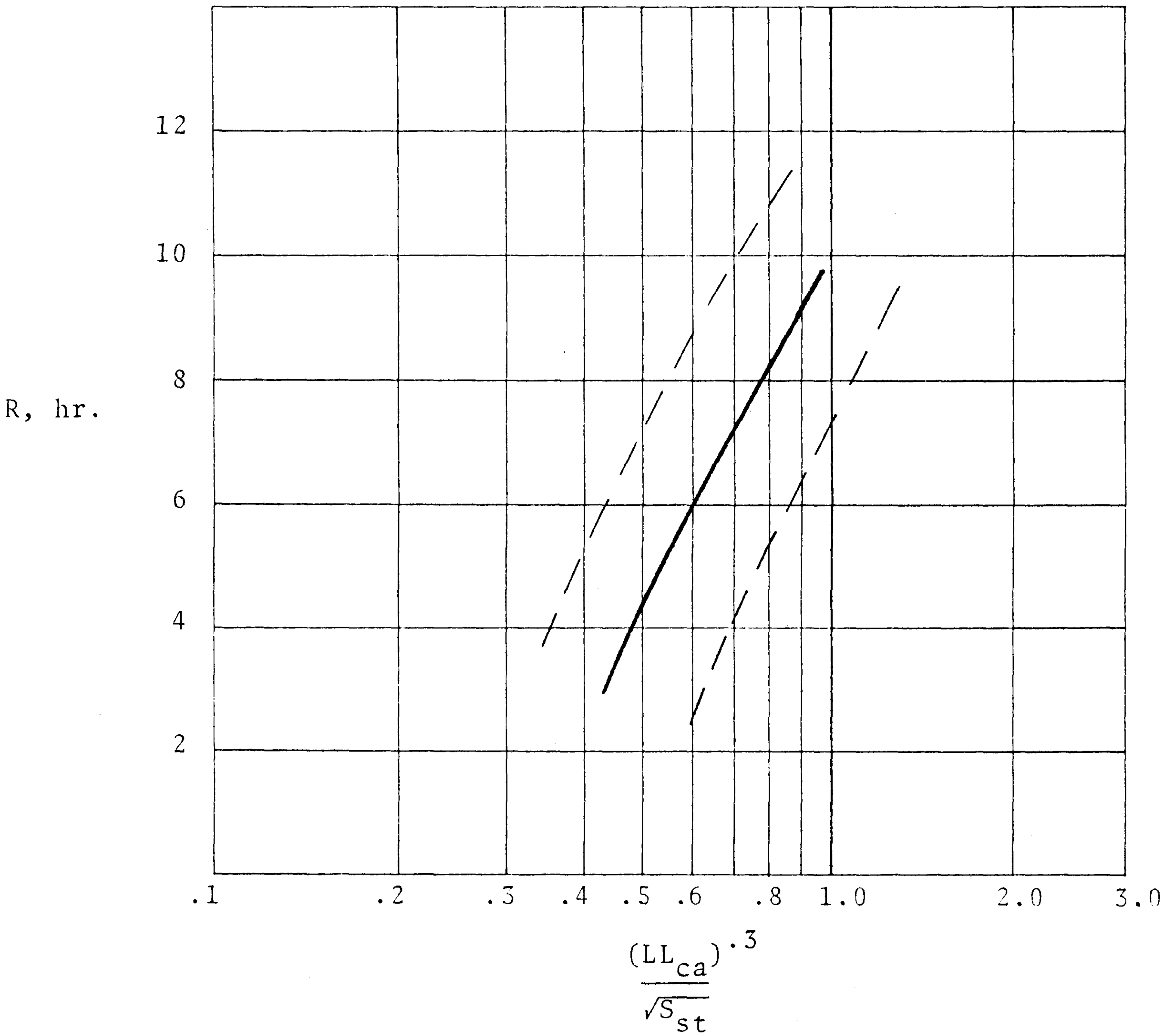


Figure A-14. Parameter selection curve, R for Region RV12.

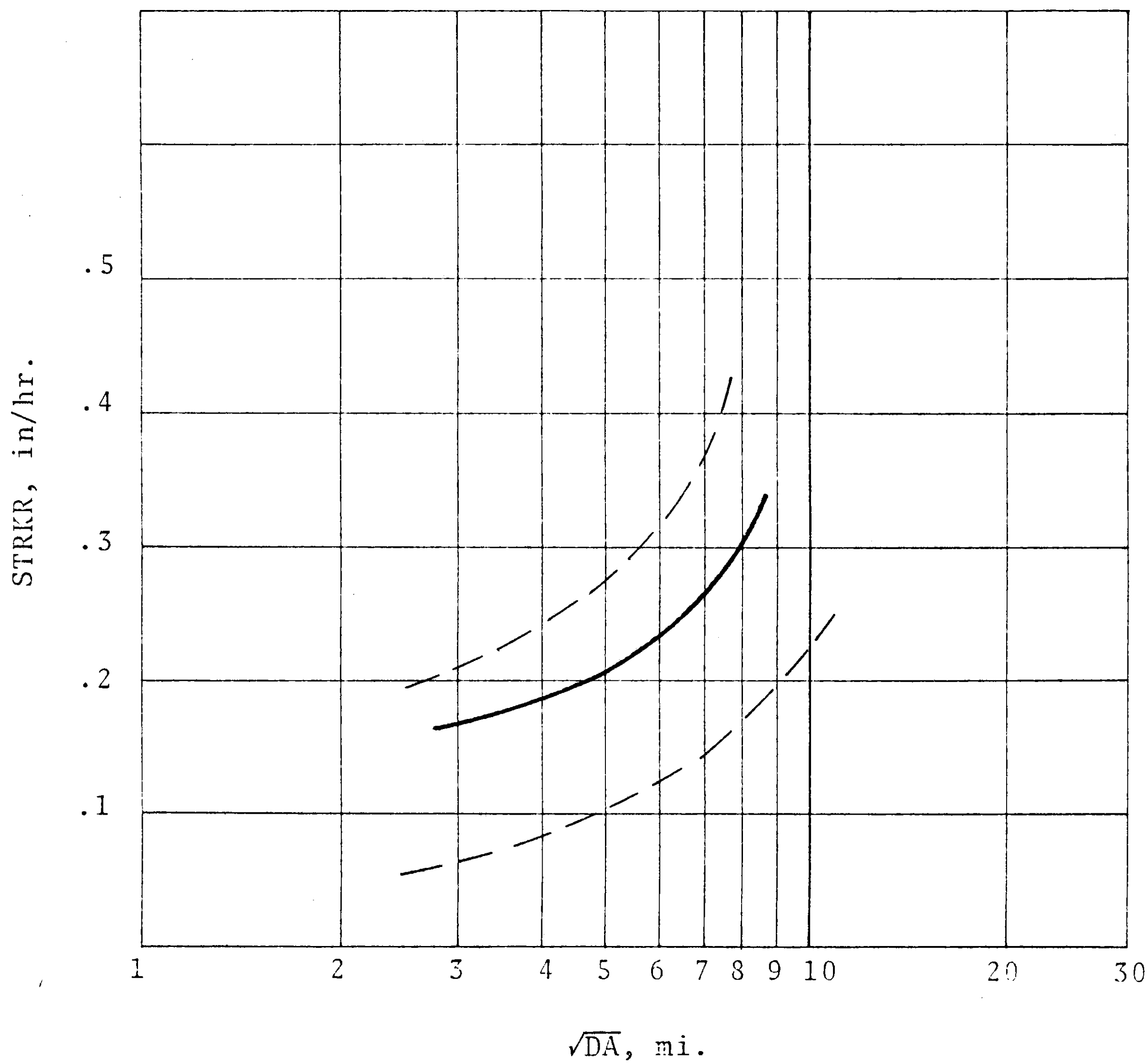


Figure A-15. Parameter selection curve, STRKR for Region RV12.

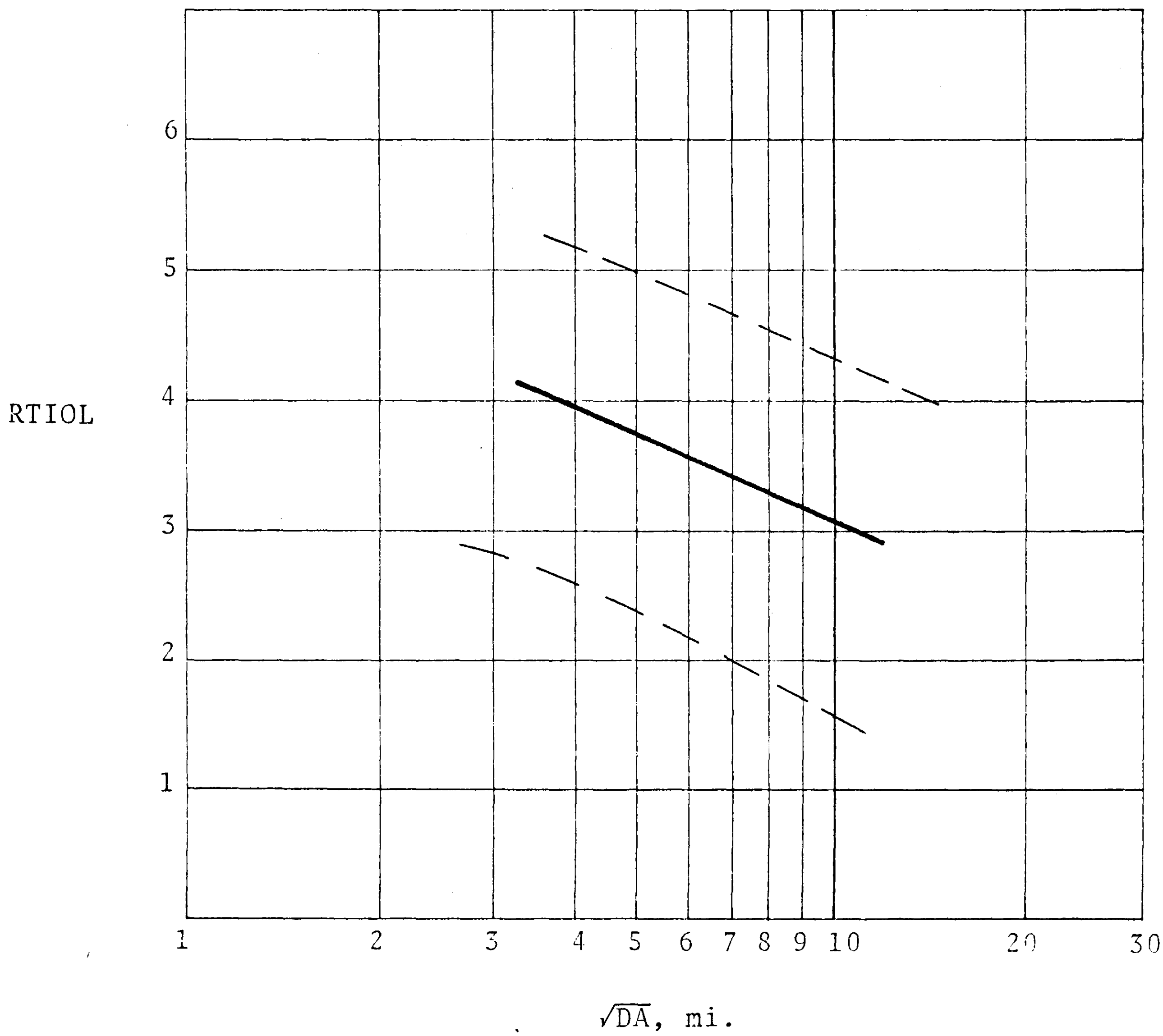


Figure A-16. Parameter selection curve, RTIOL for Region RV12.

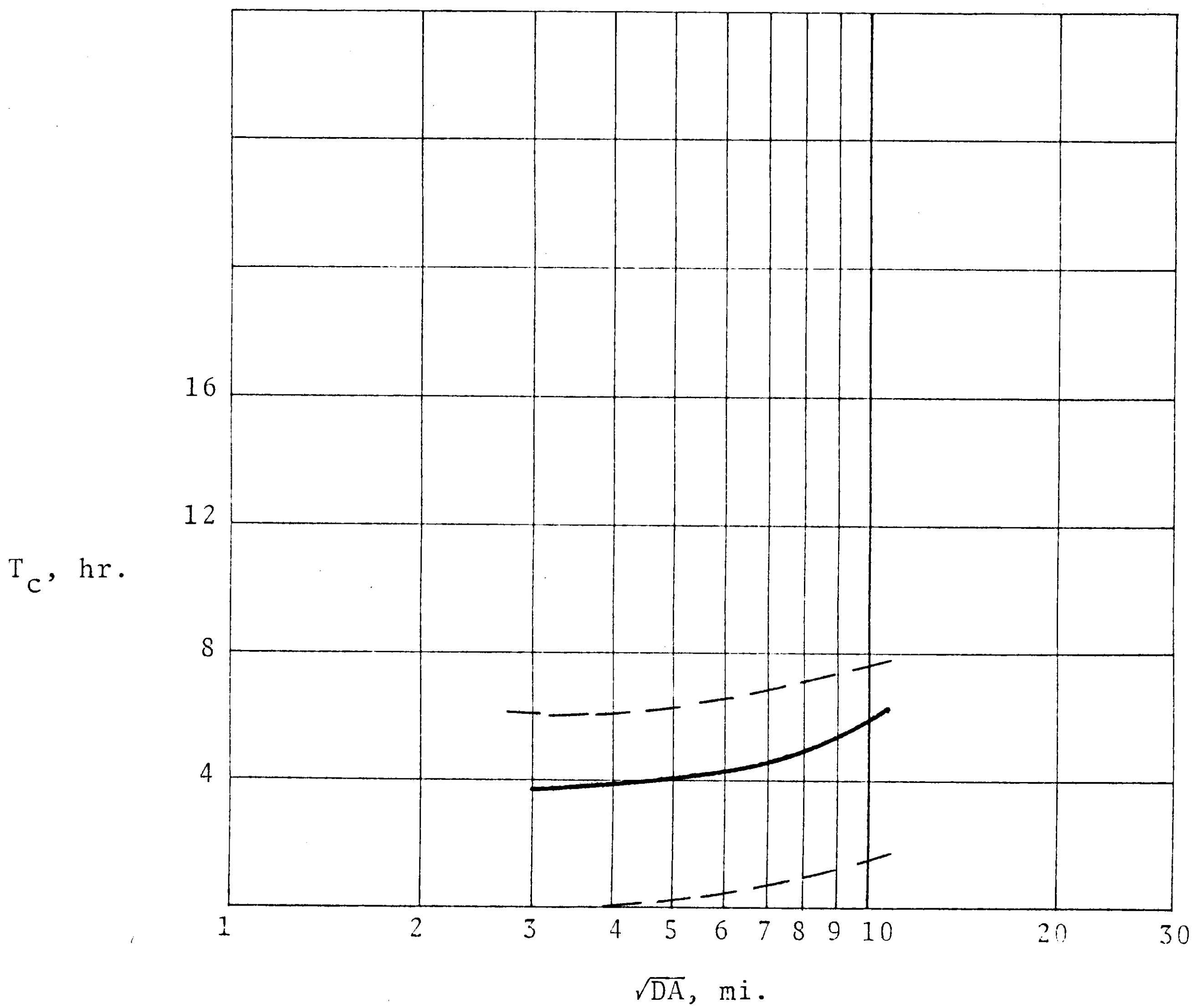


Figure A-17. Parameter selection curve, T_c for Region M2-M1.

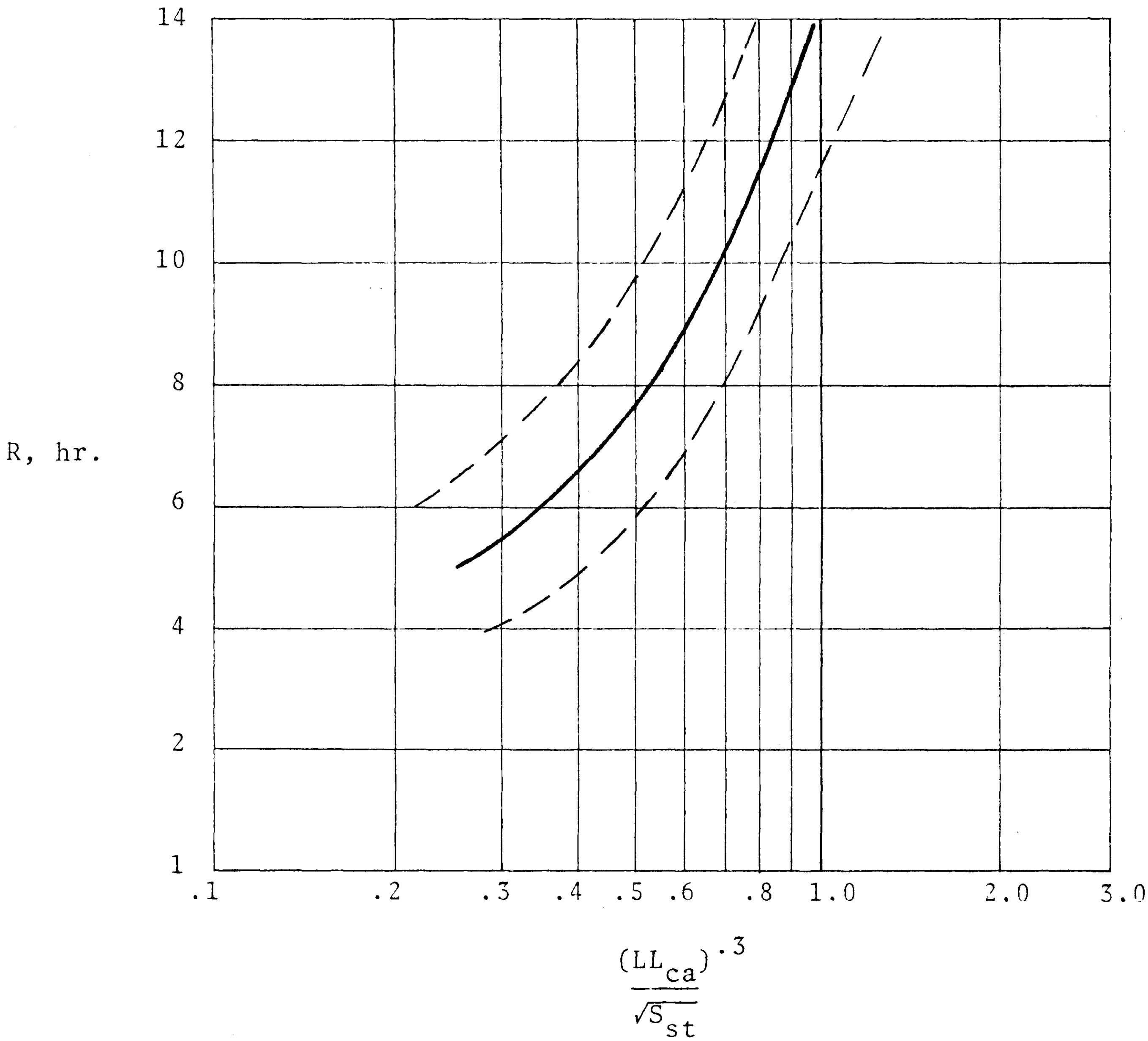


Figure A-18. Parameter selection curve, R for Region M2-M1.

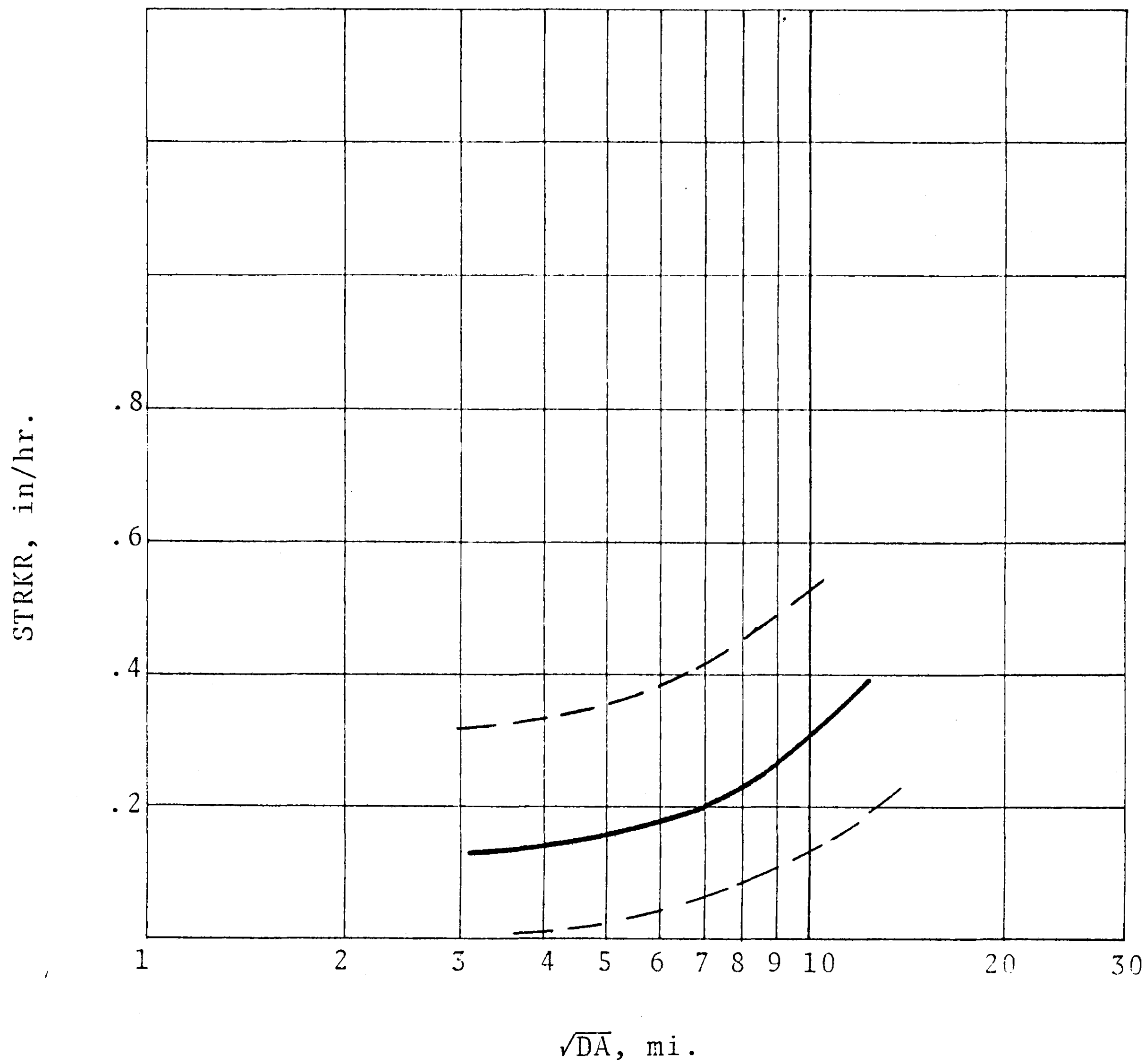


Figure A-19. Parameter selection curve, STRKR for Region M2-M1.

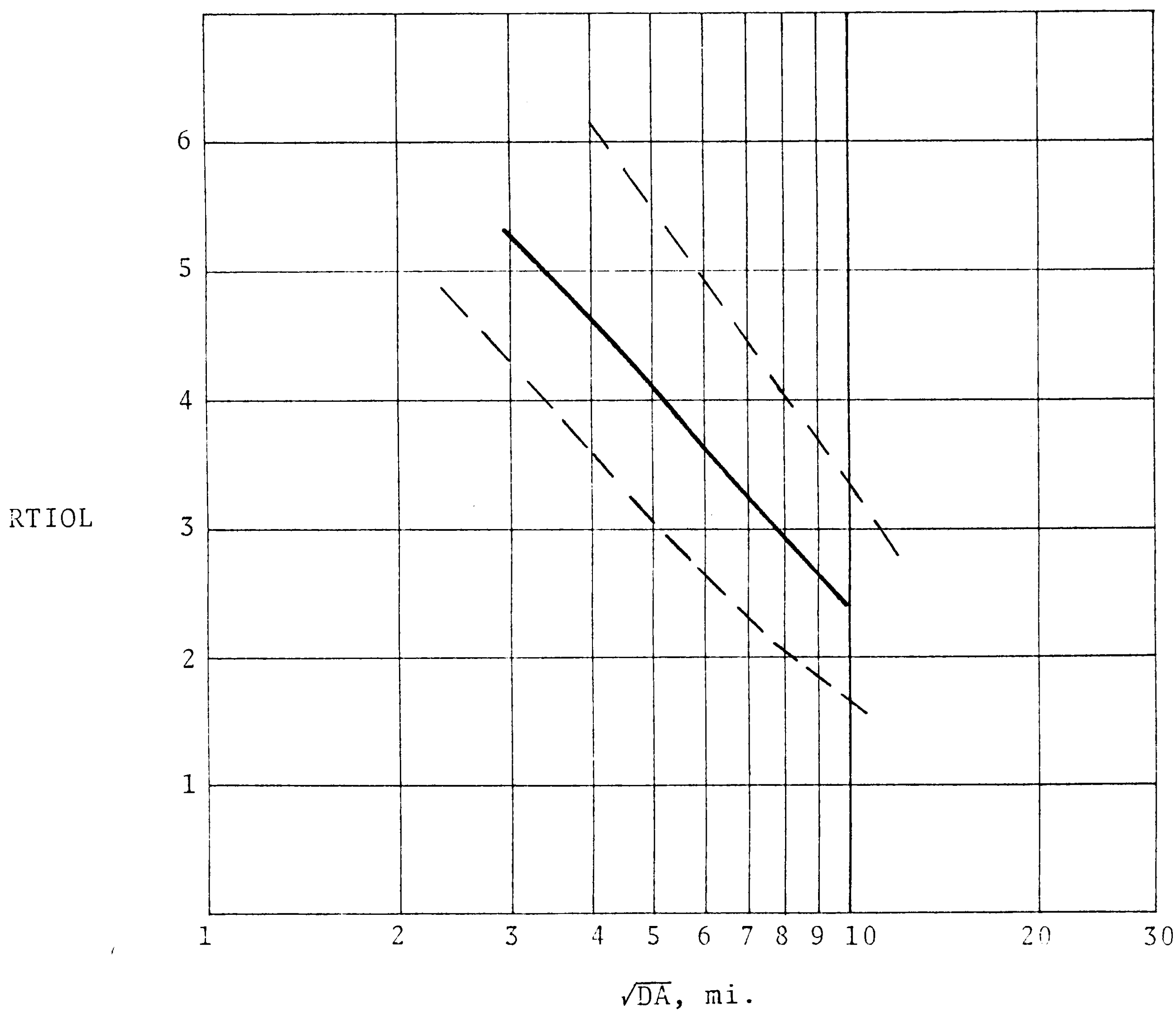


Figure A-20. Parameter selection curve, RTIOL for Region M2-M1.

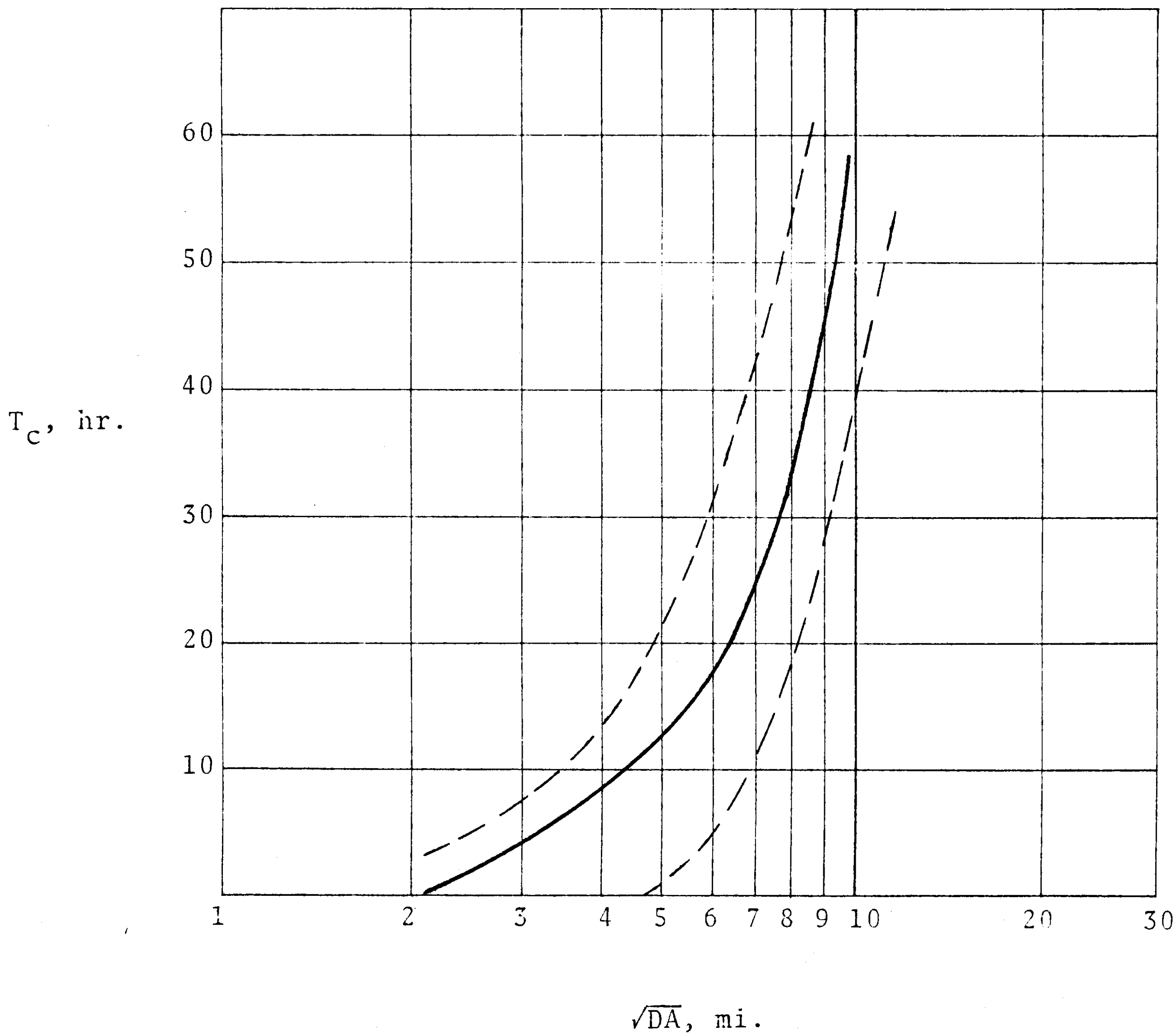


Figure A-21. Parameter selection curve, T_c for Region C1378-C25.

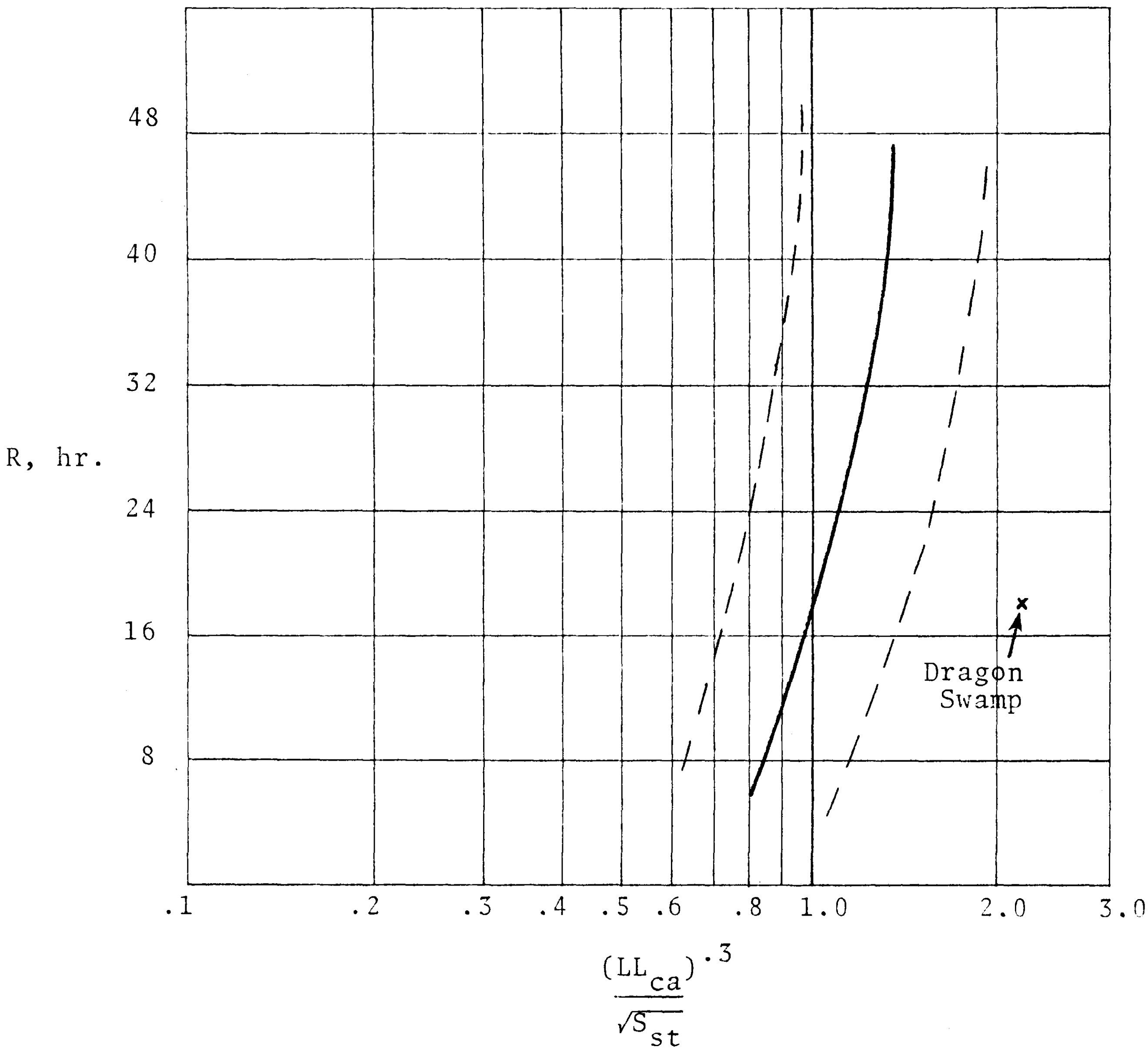


Figure A-22. Parameter selection curve, R for Region C1378-C25.

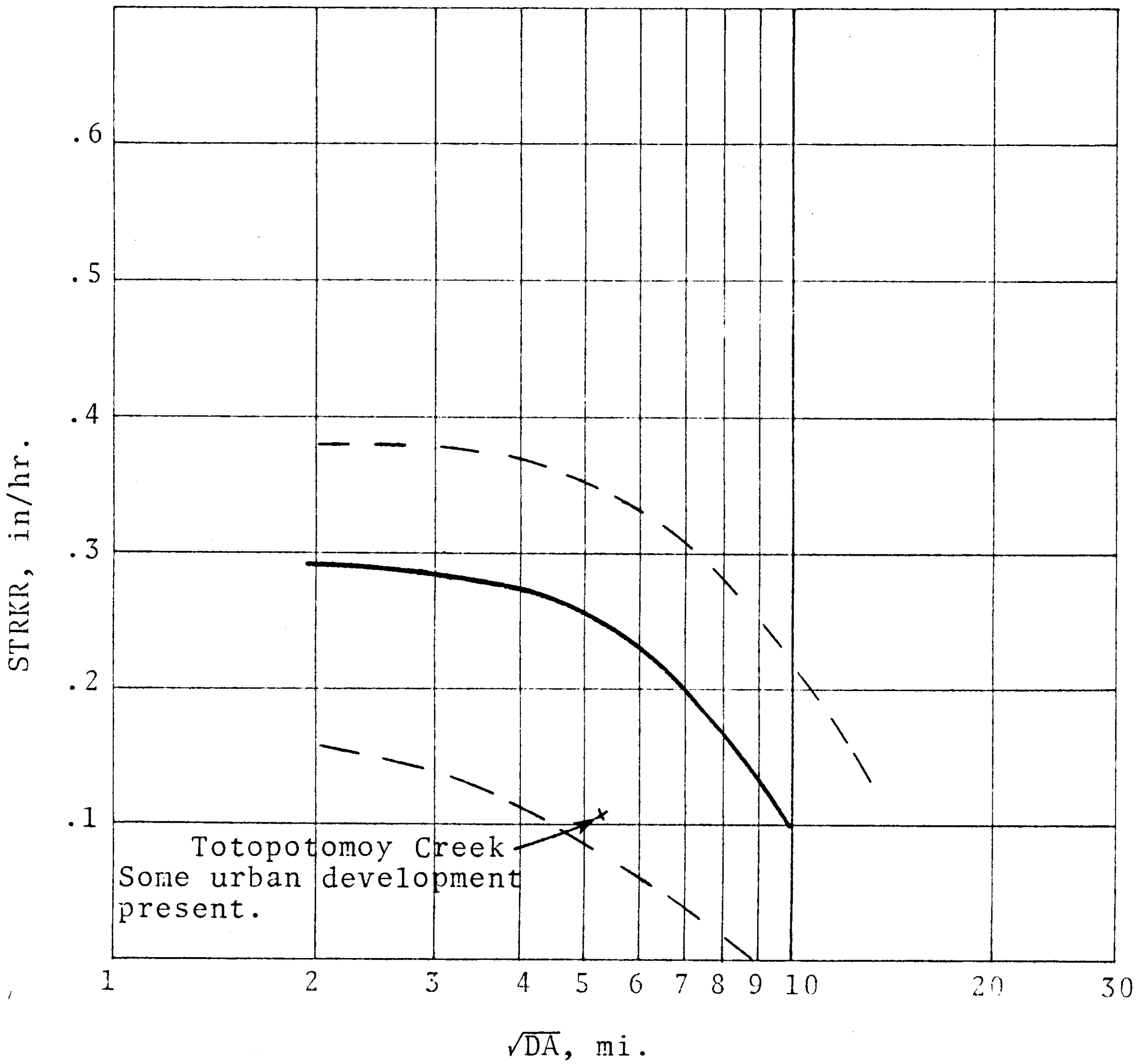


Figure A-23. Parameter selection curve, STRKR for Region C1378-C25.

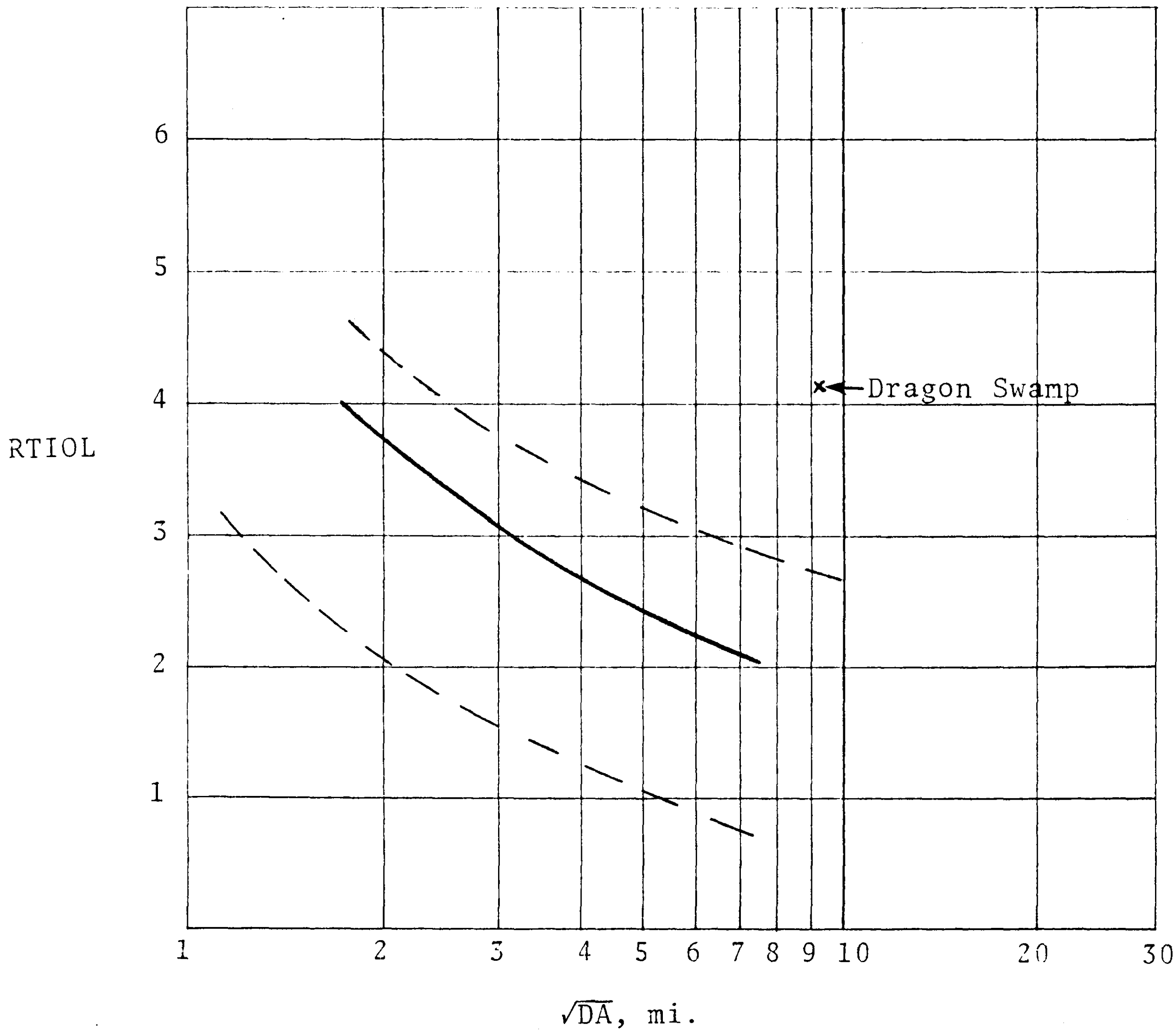


Figure A-24. Parameter selection curve, RTIOL for Region C1378-C25.

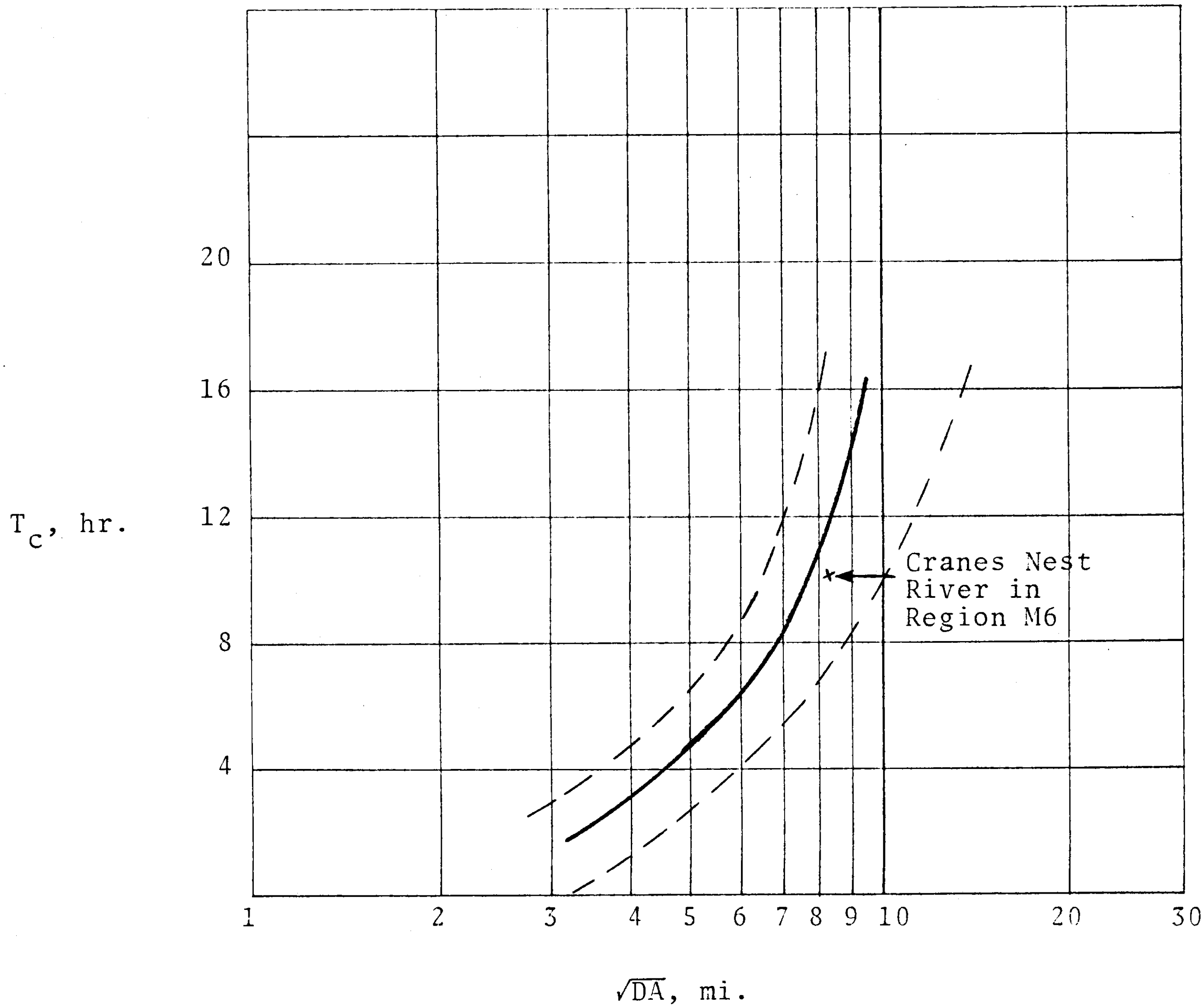


Figure A-25. Parameter selection curve, T_c for Region M649-M6.

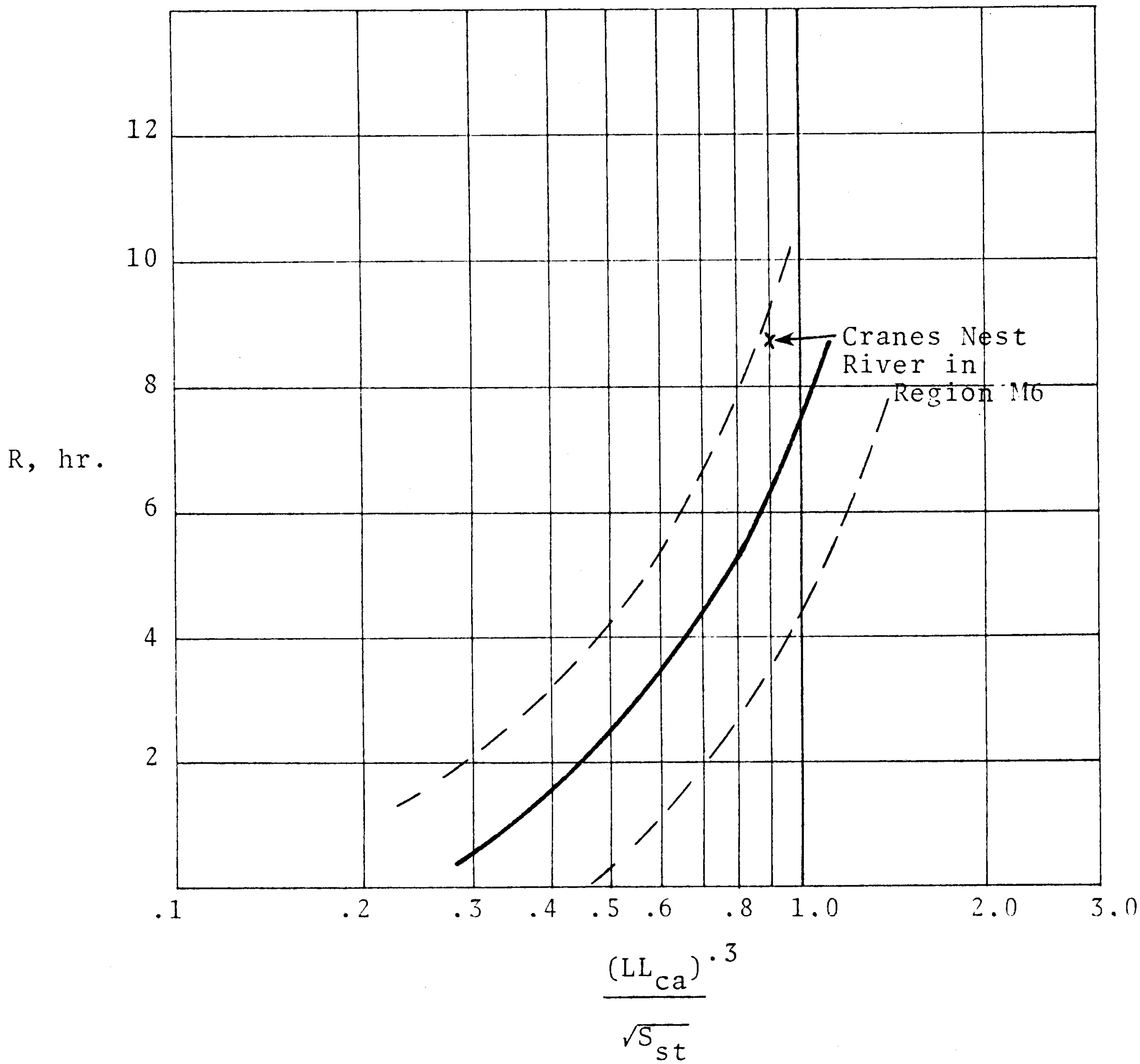
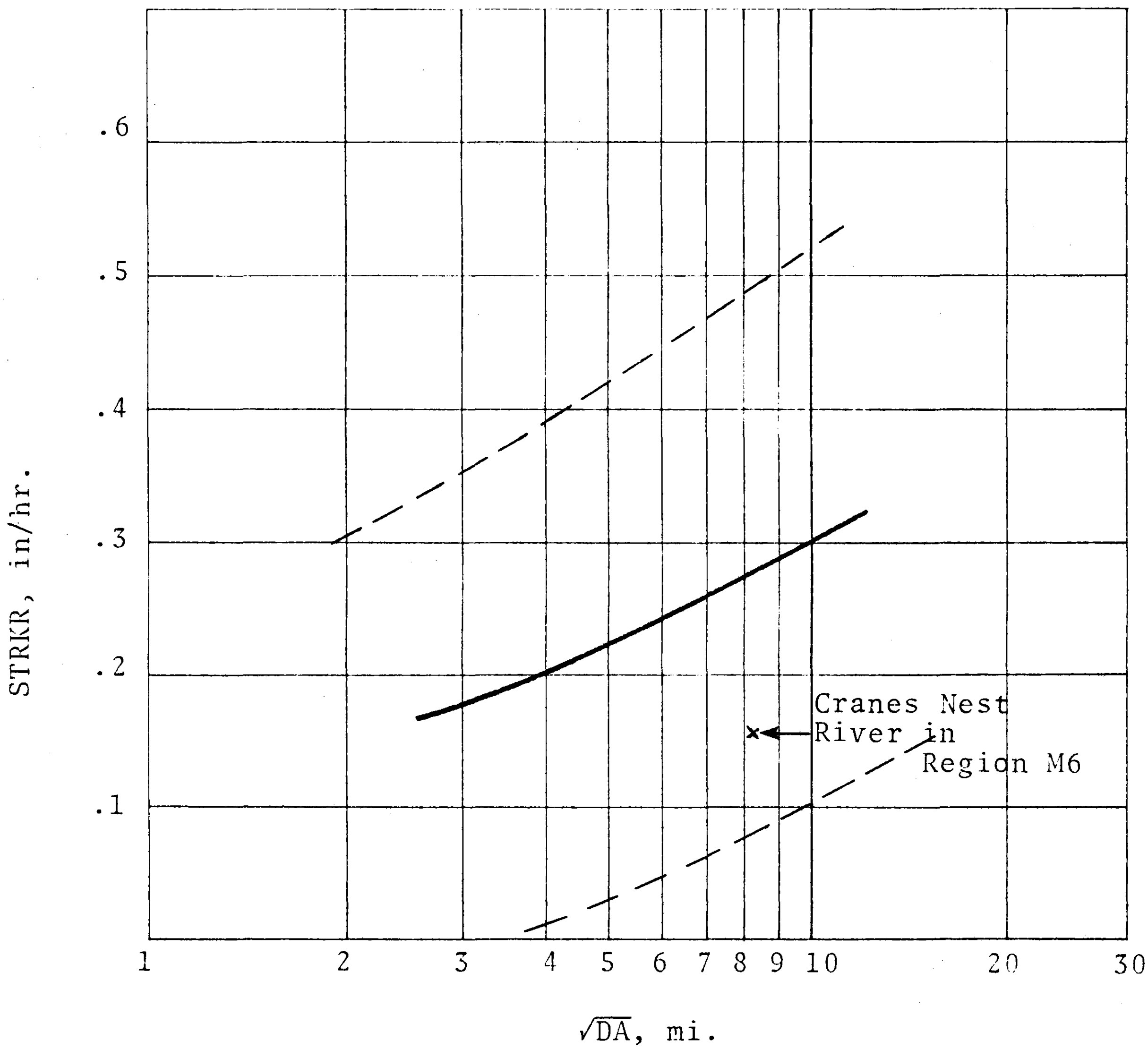


Figure A-26. Parameter selection curve, R for Region M649-M6.



Region A-27. Parameter selection curve, STRKR for Region M649-M6.

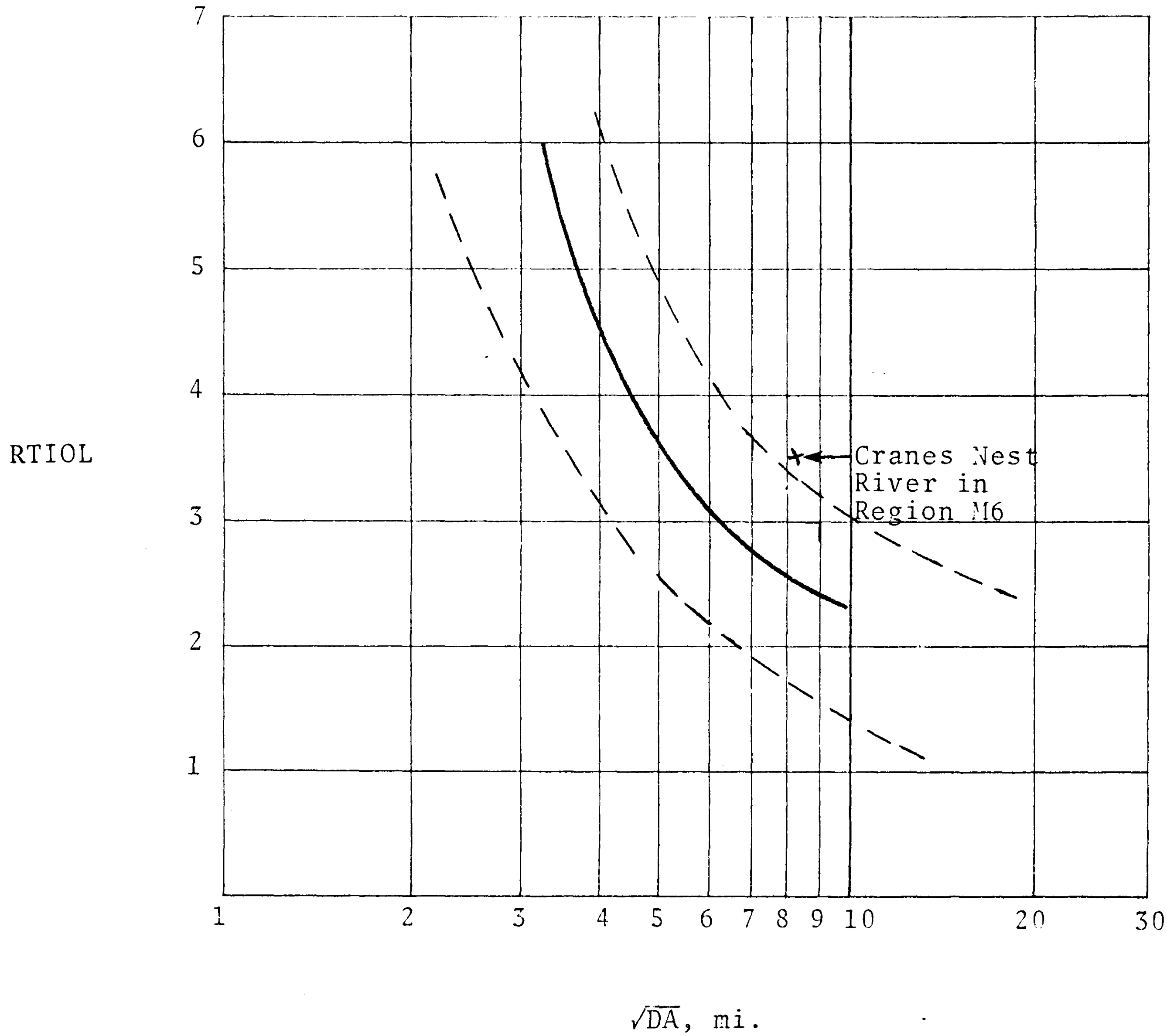


Figure A-28. Parameter selection curve, RTIOL for Region M649-M6.