APPENDIX A. LRPROP AND AVAR--AN IMPLEMENTATION OF THE ITS MODEL FOR MID-RANGE FREQUENCIES

In this appendix we give the explicit source code listing for a computer implementation of version 1.2.1 of the ITS irregular terrain model (the Longley-Rice model) for radio propagation at frequencies between 20 MHz and 20 GHz. Accompanying the listing are directions to the programmer for introducing the proper subroutines into an applications program.

The language used is FORTRAN and conforms to the 1966 ANSI standards. We believe it is also compatible with the 1977 ANSI standards. On most modern computers the routine should be usable with no modification. For satisfactorily accurate results we require floating point numbers having at least six significant decimal figures and a range at least as large as $10^{\pm 35}$.

The routines have been constructed so as to be both flexible and efficient. Redundant or unnecessary computations have been avoided, and there are no iterative processes involved. The routines may be used for either the "area prediction" mode or the "point-to-point" mode; and if the desired output consists only of the reference attenuation, one may entirely divorce the calculations from those concerned with statistics.

The two modes of operation use very similar calling sequences, and they are treated below in parallel.

Using the Longley-Rice model of radio propagation generally involves three consecutive steps: the preparation of parameters, the computation of the reference attenuation, and then the computation of selected statistics. Around these processes the programmer will put others which assemble the required input and which manipulate the resulting output. These latter we leave largely to the user's ingenuity, and in what follows we try to describe only the central three processes.

Parameter preparation is accomplished by one of two subroutines: QLRA for the area prediction mode and QLRPFL for the point-to-point mode. Also useful is the subroutine QLRPS. The reference attenuation is computed by LRPROP and the statistics by the function subprogram AVAR. Internally, most of the input and output is contained in the three common blocks /PROP/, /PROPA/, and /PROPV/. A few of the variables involved there must also be accessed directly by the user.

1. <u>Common blocks.</u>

```
COMMON/PROP/KWX,AREF,MDP,DIST,HG(2),WN,
   DH,ENS,GME,ZGND,HE(2),DL(2),THE(2)
      COMPLEX ZGND
```

This is the collection of the principal system and path parameters. It also includes the reference attenuation and an error marker. Note that all heights and distances are measured in meters.

KWX	Error marker. Indicates by its value the severity of the warning: 0 no warning 1 caution; parameters are close to limits 2 impossible parameters; default values have been substituted 3 internal calculations show parameters out of range 4 parameters out of range
AREF	Reference attenuation. This is computed by the subroutine LRPROP.
MDP	Mode of the propagation model. Values: -1 point-to-point 1 area prediction; to initialize 0 area prediction; to continue For further remarks see note 2 below.
DIST	Distance between terminals. See note 3 below.
HG	Heights of the antennas above ground.
WN	Wave number of the radio frequency.
DH	Terrain irregularity parameter.
ENS	Surface refractivity.
GME	Effective earth's curvature.
ZGND	Surface transfer impedance.
HE	Effective antenna heights.
DL	Horizon distances.
THE	Horizon elevation angles.

Note 1. The error marker KWX is meant to serve as a warning to the user that one or more of the parameters have values that make the results dubious or unusable. Except when it has the value 2, there is no effect on the computations. The value is cumulative in that after a series of calculations it will retain its highest value. Since it is never reset to 0, the user must do this himself.

Note 2. The value of MDP is handled automatically by QLRA and QLRPFL. In the area prediction mode it must first be set to 1 whereupon LRPROP will initialize various constants and set MDP to 0. On subsequent calls where it is only the distance that varies, LRPROP need not recompute those constants.

Note 3. The value of DIST is entered in two ways. In the point-to-point mode it is entered directly into /PROP/. This is done automatically by QRPFL. In the area prediction mode the distance is an actual parameter in the call to LRPROP.

```
COMMON/PROPV/LVAR,SGC,MDVAR,KLIM
```

This is the collection of instructions for treating variability in the subroutine AVAR.

LVAR — Level to which coefficients in AVAR must be defined. Each time the parameter indicated below is changed, LVAR must be set to at least:

level	parameter
0	none
1	DIST
2	HE, etc.
3	WN
4	MDVAR
5	KLIM

The subroutine AVAR will compute the necessary coefficients and reset LVAR to 0.

SGC — The standard deviation of confidence. Output by AVAR, it may be used to compute a confidence level.

MDVAR — Mode of variability calculations. Values:

- 0 Single message mode: Time, location, and situation variability are combined together to give a confidence level.
- 1 Individual mode: Reliability is given by time availability. Confidence is a combination of location and situation variability.
- 2 Mobile mode: Reliability is a combination of time and location variability. Confidence is given by the situation variability.
- 3 Broadcast mode: Reliability is given by the two-fold statement of <u>at least</u> q_T of the time in q_L of the locations. Confidence is given by the situation variability.

In addition, to these values may be added either or both of the numbers 10 and 20 with the meanings:

- +10 Location variability is to be eliminated as it should when a well-engineered path is being treated in the point-to-point mode.
- +20 Direct situation variability is to be eliminated as it should when considering interference problems. Note that there may still be a small residual situation variability.

KLIM — Climate code. Values:

- 1 Equatorial
- 2 Continental subtropical
- 3 Maritime subtropical
- 4 Desert
- 5 Continental temperate
- 6 Maritime temperate over land
- 7 Maritime temperate over sea

```
COMMON/PROPA/DLSA,DX,AEL,AK1,AK2,AED,EMD,AES,EMS,
   DLS(2),DLA,THA
```

The collection of parameters and coefficients which define the reference attenuation as a function of distance. Ordinarily of no interest to the user.

```
COMMON/SAVE/...
```

A collection of miscellaneous constants and coefficients which must remain defined in certain of the subroutines. Used in place of the SAVE directive and of no interest to the user.

2. Parameter preparation.

The reference attenuation requires the variables

MDP, DIST, HG, WN, DH, ENS, GME, ZGND, HE, DL, THE

and also an attention to KWX. The statistics require the variables

MDVAR, KLIM, ZT, ZL, ZC

and also an attention to LVAR; note that the value of MDVAR determines the meanings of ZT, ZL, ZC. The following subroutines should be used to introduce many of these variables.

```
CALL QLRPS(FMHZ,ZSYS,EN0,IPOL,EPS,SGM)
```

This will define WN, ENS, GME, ZGND in /PROP/

FMHZ	Frequency in MHz.
ZSYS	Average elevation above sea level of the system; if 0, EN0 will be interpreted as ENS.
EN0	Minimum monthly mean surface refractivity reduced to sea level; if it is desired to introduce ENS instead, then set ZSYS=0.
IPOL	Polarization code: 0, horizontal; 1, vertical.
EPS,SGM	Ground constants.

```
CALL QLRA(KST,KLIM,MDVAR)
```

Prepares parameters for the area prediction mode. Prior to this call one should define HG, DH and WN, ENS, GME, ZGND in /PROP/. The present routine will then define HE, DL, THE, LVAR, and optionally KLIM, MDVAR. It sets MDP=1.

KST	Siting criterion code for each terminal; an array of length 2.
KLIM	Climate code. If greater than 0, the routine will put this value in /PROPV/ and set LVAR=5.
MDVAR	Mode of variability. If non-negative, the routine will put this value in /PROPV/ and set LVAR to at least 4.

In any case, the routine sets LVAR to at least 3.

```
CALL QLRPFL(PFL,KLIM,MDVAR)
```

Prepares parameters for the point-to-point mode and calls LRPROP thus defining also the reference attenuation AREF. Prior to this call one should define HG and WN, ENS, GME, ZGND in /PROP/. One should also have prepared a terrain profile in the array PFL. For this we imagine a sequence of elevations p_o, p_1,..., p_{np} taken at equal intervals ξ from the point under the first terminal to that under the second. Note that the path distance is then $n_p\xi$.

PFL	Terrain profile. An array packed with the values n_p, ξ, p_o, ..., p_{np}, in that order. Thus PFL(1) is the floating point representation of n_p, PFL(2) equals the interval ξ between profile points, and PFL(i+3) equals p_i, i=0, ..., n_p, i.e., the elevation of the point distant $i\xi$ from the first terminal. The total length of the array is n_p+3.
KLIM	Climate code. If greater than 0, the routine will put this value in /PROPV/ and set LVAR=5.
MDVAR	Mode of variability. If non-negative, the routine will put this value in /PROPV/ and set LVAR to at least 4.

In any case the routine sets LVAR to at least 3.

It should be noted that the Longley-Rice model is silent on many of the details for defining some of the path parameters. This is particularly true of the effective heights $h_{el,2}$ and, to some lesser degree, of the terrain irregularity parameter Δh. The effective height, for example, is defined as the height above the "effective reflecting plane," and in the past the investigator has been urged to use his own best judgment as to where that plane should be placed. The subroutine QLRPFL, in trying to automate the definition of all parameters, has been forced to define explicitly all missing details. It has done this in a way that seems reasonable and in full accord with the intent of the model. These techniques should not, however, be construed to have any "official" standing.

3. The reference attenuation.

After defining all necessary parameters, the next step is to compute the reference attenuation. This is done by a single call.

```
CALL LRPROP(D)
```

This will define the reference attenuation AREF in /PROP/. Prior to this call one should have defined MDP, WN, HG, DH, ENS, GME, ZGND, HE, DL, THE in /PROP/. In the point-to-point mode (when MDP=-1), the distance should also have been defined as DIST in /PROP/. The formal parameter D will be ignored. In the area prediction mode (when MDP=1 or 0), D represents the distance and LRPROP will replace DIST in /PROP/ by this value. Also, on the first entry after a set of parameters has been defined, one should set MDP=1. Then LRPROP will set switches, define certain constants, and reset MDP to 0. On subsequent calls, if it is only the distance that changes, one should not redefine MDP.

In the area prediction mode there is also a special call obtained by setting D=0. In general, a call to LRPROP will result in the definition of only those coefficients that are necessary to compute the reference attenuation at the indicated distance. In this special call, however, all coefficients in /PROPA/ will be defined. If desired, the user can then consider these coefficients to be additional output from LRPROP.

4. Statistics.

Statistics are available through the function subprogram AVAR in the form of quantiles--i.e., values of attenuation which are not exceeded for a fraction q of the samples. Rather than using the fraction q directly, however, we convert our terminology to an equivalent standard normal deviate z defined by

$$q = Q(z) = (2\pi)^{-1/2} \int_z^\infty e^{-t^2/2}\, dt \quad .$$

The function Q is the complementary normal probability function as defined in most texts on statistics. This standard normal deviate is used because the random variables involved are all normally distributed or very nearly normally distributed, and calculations using them are greatly simplified. We use the complementary function rather than the direct function because we usually think in terms of a received signal level rather than a loss or an attenuation and would like to say that this level is at least so large for a fraction q=Q(z) of the samples.

Note that Q is a monotonically decreasing function and that as q goes from 0 to 1, z goes from ∞ to $-\infty$. For example, Q(0)=0.5, Q(1.28155)=0.1, and Q(-1.28155)=0.9.

Before using AVAR, one should have defined all system and path parameters in /PROP/ and also the reference attenuation AREF. In addition, one should define LVAR, MDVAR, KLIM in /PROPV/.

Then the function AVAR can be evaluated. It has three formal parameters whose meanings are determined by the mode of variability as specified in MDVAR. In what follows we use freely a notation such as QC, ZC to indicate a pair consisting of a probability and its corresponding standard normal deviate.

Single message mode (MDVAR=0).

A=AVAR(0.,0.,ZC)

Then with confidence QC the attenuation will not exceed A. The first two parameters are unused.

Individual and mobile modes (MDVAR=1 or 2).

A=AVAR(ZR,0.,ZC)

Then with confidence QC the attenuation will not exceed A with a reliability at least as large as QR. The second of the three parameters is unused.

Broadcast mode (MDVAR=3).

A=AVAR(ZT,ZL,ZC)

Then with confidence QC there will be at least QL of the locations where the attenuation will not exceed A for at least QT of the time.

In addition to AVAR there are two small function subprograms which, if desired, can be used to facilitate the translation between probabilities and standard normal deviates.

Q=QERF(Z)

Z=QERFI(Q)

These are the Q error function and the inverse of the Q error function respectively.

5. Suggested operational flow.

```
TO USE THE AREA PREDICTION MODE
   SET KWX = 0
   DEFINE HG, DH AND CALL QLRPS
   OPTIONALLY, DEFINE MDVAR, KLIM
   CALL QLRA
   LOOP FOR SELECTED DISTANCES D
   ↑  SET LVAR = MAX(LVAR,1)
   ↑  CALL LRPROP(D)
   ↑  LOOP FOR SELECTED QUANTILES
   ↑  ↑  A = AVAR(...)
   ↑  ↑  OUTPUT A
   ↑  ↑--REPEAT
   ↑--REPEAT
   CHECK KWX
   ENDTO
```

```
TO USE THE POINT-TO-POINT MODE
   SET KWX = 0
   DEFINE PFL, HG AND CALL QLRPS
   OPTIONALLY, DEFINE MDVAR, KLIM
   CALL QLRPFL
   LOOP FOR SELECTED QUANTILES
   ↑  A = AVAR(...)
   ↑  OUTPUT A
   ↑--REPEAT
   CHECK KWX
   ENDTO
```

6. Source code listings.

The subprograms on the following pages are arranged in logical order. First is LRPROP followed by several ancillary subprograms. Then comes AVAR followed by the additional routines QERF and QERFI. The last group consists of the preparatory routines QLRPS, QLRA, and QLRPFL, the latter followed by several ancillary subprograms.