3. PARAMETERS AND EQUATIONS

This section describes the research and equations used in RWEQ, which estimates soil eroded and transported by wind between the soil surface and a height of two meters. Fine sediment is transported as suspended load and travels much greater distances than the coarse sediment transported as creep and saltation. Thus, RWEQ is not applicable for those problems where suspended, fine sediment above two meters is the concern. RWEQ is most applicable for problems of erosion from the field, but can also provide information on erosion rate effects within the field and abrasion of plants by wind blown sediment. The intent of this section is to discuss the equation used to estimate transport mass and the equations used to input weather, soils, crops, and tillage data into the RWEQ model. In addition, the computations of erosion from validation sites in several states are included to compare measured erosion under a variety of conditions with RWEQ estimated erosion.

3.1 TRANSPORT MASS EQUATION

The heart of any wind erosion model is the equation for computing the mass transport of wind-eroded material. Mass transport (*Q*) varies with soil texture, soil surface, field length, and climatic conditions (Fryrear and Saleh, 1996; Stout and Zobeck, 1996). Transport equations have been developed and applied to the movement of agricultural soils (Gregory and Borelli, 1986; Stout, 1990; Hagen and Armbrust, 1994), desert sands, and windblown snow (Greeley and Iversen, 1985). One common feature of these equations is the assumption that the horizontal flux is proportional to the difference between the maximum transport and the actual transport at a point within the field.

Horizontal mass transport across an eroding surface has been measured by Bagnold (1943), Chepil (1945), Fryrear *et al.* (1991), Fryrear and Saleh (1996), and Stout (1990). The basic equation that defines the horizontal distribution of transport mass $Q(x)$ is

$$b(x)\,\frac{dQ(x)}{dx} + Q(x) - Q_{max}(x) + S_r(x) = 0 \qquad [1]$$

where

$Q(x)$	=	mass transport at downwind distance *x*, kg/meter-width
$Q_{max}(x)$	=	maximum transport, kg/meter-width
$S_r(x)$	=	surface retention coefficient
x	=	distance from the upwind edge of the field, meters
$b(x)$	=	field length scale, meters.

Fryrear, D.W., Ali Saleh, J.D. Bilbro, H.M. Schomberg, J.E. Stout, and T.M. Zobeck. 1998. Revised Wind Erosion Equation (RWEQ). Wind Erosion and Water Conservation Research Unit, USDA-ARS, Southern Plains Area Cropping Systems Research Laboratory. Technical Bulletin No. 1. Internet address: http://www.csrl.ars.usda.gov/wewc/rweq.htm

In RWEQ, $S_r(x)$ is set to zero and thus equation **[1]** may be rewritten as

$$\frac{dQ(x)}{dx} = \frac{Q_{max}(x) - Q(x)}{b(x)} \quad . \qquad \textbf{[2]}$$

Equation **[2]** can be solved analytically in a few special cases. For the special case where Q_{max} and b are constant (the simple field assumption), the solution of equation **[2]** is simply

$$\frac{Q(x)}{Q_{max}} = 1 - e^{-\left(\frac{x}{b}\right)} \quad . \qquad \textbf{[3]}$$

On the other hand, if we assume that the length scale b varies with distance across the field or $b=b(x)$ then there are many other possible solutions. For example, if we assume that

$$b(x) = \frac{s(x)^2}{2x} \qquad \textbf{[4]}$$

where $s(x)$ is a field length scale, then equation **[2]** becomes

$$\frac{dQ(x)}{dx} = \frac{2x}{s(x)^2}\left(Q_{max}(x) - Q(x)\right) \qquad \textbf{[5]}$$

which is the governing equation used in RWEQ. For the special case where Q_{max} and s are constant, we obtain the sigmoidal form:

$$\frac{Q(x)}{Q_{max}} = 1 - e^{-\left(\frac{x}{s}\right)^2} \quad . \qquad \textbf{[6]}$$

Note from equation **[6]**, when $x = s$ and s is the critical field length, $Q(s)$ = 63.2% of Q_{max}.

The first derivative of $Q(x)$ with respect to x defines the soil loss at each point across a wind-eroding surface. From equation **[5]** we find that

$$soil\ loss = \frac{dQ(x)}{dx} = \frac{2x}{s(x)^2}\left(Q_{max}(x) - Q(x)\right) \quad . \qquad \textbf{[7]}$$

In equation **[8]** we can combine equations **[5]** and **[6]** to obtain soil loss for the special case where Q_{max} and s are constant (not functions of x).

$$soil\ loss = \frac{2x}{s^2} Q_{max} e^{-\left(\frac{x}{s}\right)^2} \qquad \textbf{[8]}$$

Where soil roughness is the same upwind and within the field of interest, equation **[3]** appears to best describe measured data. However, few actual fields fit the ideal, thus, equation **[6]** often has smaller residual sums of squares than equation **[3]** when fit to measured data. Beyond a distance *x* greater than *s*, the two equations give almost identical results, especially when fit to experimental data where field length extends beyond the distance *s*. However, if the field length is less than *s*, then the appropriate equation depends on upwind conditions. In particular, if surface conditions upwind of a field have increased roughness or vegetative cover and the erosivity of the wind is dramatically reduced, then equation **[6]** is often found to better describe measured data.

Although equation **[5]** can be solved analytically in a few special cases, in RWEQ it is solved numerically. First, we approximate the mass transport gradient in finite difference form as

$$\frac{dQ(x)}{dx} \approx \frac{Q(x+\Delta x) - Q(x)}{\Delta x} \quad . \qquad \textbf{[9]}$$

Combining equations **[5]** and **[9]** yields the finite difference equation which is used in RWEQ:

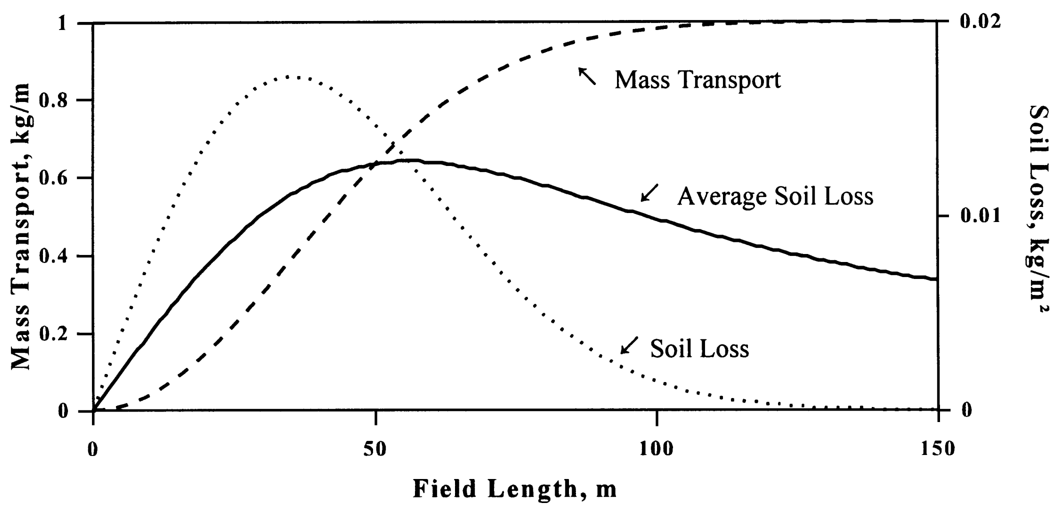
$$Q(x+\Delta x) = Q(x) + \left(\frac{Q_{max}(x) - Q(x)}{s(x)}\right)\left(\frac{2x}{s(x)}\right)\Delta \quad . \qquad \textbf{[10]}$$

An example plot of soil loss across a field with $s = 50$ meters is shown in Figure 3.1. The maximum soil loss occurs at a downwind distance of $x = s\sqrt{2}$ or in this case at $x = 35.4$ m. Soil loss approaches zero as mass transport approaches the maximum mass transport Q_{max} ; in this example, this occurs at a downwind distance of around 150 m.

To express erosion in terms that can be compared to the output from WEQ, average soil loss is defined as mass transport at field length *x* or *Q(x)* divided by distance *x*. In this example, maximum average soil loss occurs at a downwind distance equal to 55 m. After reaching a maximum, average soil loss decreases with increasing field length and is 0.0067 kg/m^2 at a field length of 150 m.

Variations in transport mass within large fields may be due to different residue levels, tillage roughness conditions or erodibility of the soil surface (Chepil, 1957) (Fryrear and Saleh, 1996). The mass of eroded soil material being transported by wind depends on the magnitude and duration of the wind speed, soil erodibility, orientation and quantity of crop residues, and the type, timing and number of tillage operations. In the following sections the coefficients for weather, soils, crops, and tillage used to calculate Q_{max} and s are described.

Figure 3.1 Relationship between mass transport, soil loss, and average soil loss from RWEQ using $s = 50$ m and $Q_{max} = 1.0$ kg/m.



3.2 WEATHER EQUATIONS

3.2.1 Wind value (W)

Wind is the basic driving force in RWEQ. To estimate soil erosion an accurate input of the wind is required. Bagnold (1943) and Zingg (1953) used the friction speed cubed to describe the relationship between wind speed and mass transported. Ten mass transport equations using friction speed cubed and four mass transport equations using wind speed cubed are listed in Greeley and Iverson's Table 3.5 (1985). To compute friction speed the roughness of the surface must be described. Since soil roughness, residue levels, wind barriers and soil texture are highly variable, a reference wind speed above the immediate surface boundary was used. The field measurements are from relatively smooth surfaces; therefore, the instrumented reference height is 2 meters.

RWEQ expresses the wind in a form that uses wind speed minus the threshold speed. The equation for calculating the wind value is

$$W = \sum_{i=1}^{N} U_2 (U_2 - U_t)^2 \qquad \textbf{[11]}$$

where

W	=	wind value, (m/sec)^3
U_2	=	wind speed at 2 meters, m/sec
U_t	=	threshold wind speed at 2 meters (assumed 5 m/sec)
N	=	number of wind speed observations (*i*) in a time period of 1-15 days.

Combinations of wind speed (U_2) and threshold wind speed (U_t) that were considered for use in RWEQ gave the following wind values.

	$U_2^2(U_2-U_t)$	$U_2(U_2^2-U_t^2)$	$\mathbf{U_2(U_2-U_t)^2}$	$(U_2-U_t)U_t^2$
W when U_2 = 6 m/sec	36	66	**6**	25
W when U_2 = 20 m/sec	6000	7500	**4500**	375
ratio of W when U_2 = 20 to W when U_2 = 6	167	114	**750**	15

The bolded expression was chosen because it gives the largest range of wind values (W) when U_2 varies from 6 to 20 m/sec.

3.2.2 **Wind factor (*Wf*)**

Over 600 weather data files were assembled for RWEQ using procedures described by Skidmore and Tatarko (1990; Appendix Q). In these weather files, the wind is described with Weibull coefficients *k* and *c*, percent calm, and the cumulative probability distribution. The RWEQ program divides the probability values that range from 0 and 0.999 into 500 uniformly distributed probability values. These probability values are used with the Weibull coefficients and percent calm to compute 500 wind speeds for each period. These computed 10-meter wind speeds are converted to the equivalent 2-meter wind speeds, then the wind factor (*Wf*) is computed.

The total wind factor (*Wf*) for each period is determined by dividing the total wind value for each period by 500 and multiplying by the number of days in the period.

$$Wf = \frac{W}{500} \times N_d \qquad \textbf{[12]}$$

where

Wf	=	wind factor, (m/sec)^3
W	=	wind value, (m/sec)^3
N_d	=	number of days in the period.

The selection of 500 for the number of uniformly distributed probability values was based on the minimal difference in *Wf* when 10 to 10,000 uniformly distributed probability values are used to compute the wind factor in equation **[12]**.

Number of probability values	10	50	100	300	500	750	1,000	10,000
Wf, $(m/sec)^3$	119	233	218	248	238	241	240	241

Integration of the wind speed probability distribution equation would provide a single wind factor for each time period. However, a single wind factor excludes the computation of wind speeds for expressing windbarrier and hill effects. See equations **[30]** and **[31]**.

3.2.3 Weather factor (*WF*)

Wf is combined with terms for soil wetness (*SW*) and snow cover (*SD*) to produce a weather factor (*WF*).

$$WF = Wf \frac{\rho}{g} (SW)\, SD \qquad [13]$$

where

WF = weather factor, kg/m
Wf = wind factor, $(m/sec)^3$
ρ = air density, kg/m^3
g = acceleration due to gravity, m/sec/sec
SW = soil wetness, dimensionless
SD = snow cover factor.

WF is then partitioned according to the preponderance and positive parallel ratio values from the weather file (Skidmore and Tatarko, 1990; Skidmore *et al.*, 1995). While *WF* has the same terms as the climatic factor in WEQ, *WF* also contains terms for threshold speeds and snow cover.

3.2.3.1 Soil wetness (*SW*)

The wetness of the surface influences the wind speed required to erode the soil (Chepil, 1956; Saleh and Fryrear, 1995). The duration of the benefits from a wet soil surface depends on evaporative demand of the atmosphere, but wind erosion can follow rainstorms within a few minutes.

The soil wetness factor developed for RWEQ is

$$SW = \frac{ET_p - (R + I)\dfrac{R_d}{N_d}}{ET_p} \qquad [14]$$

where

SW = soil wetness factor
ET_p = potential relative evapotranspiration, mm
R_d = number of rainfall and/or irrigation days
$R+I$ = rainfall and irrigation, mm
N_d = number of days (normally 15).

The equation for computing ET_p reported by Samani and Pessarakli (1986) is

$$ET_p = 0.0162 \left(\frac{SR}{58.5} \right) (DT + 17.8) \qquad \textbf{[15]}$$

where

SR = total solar radiation for the time period, cal/cm^2
DT = average temperature, degrees centigrade.

Soil wetness increases the resistance of the soil surface to wind erosion. If there is more rain or irrigation than solar radiation can evaporate, then the soil wetness factor is zero and there is no erosion for that period. With no rain or irrigation, the soil wetness factor is 1.0 for that period regardless of the previous period's conditions.

The influence of soil wetness on a fine sandy loam soil was evaluated in the 1990 wind erosion season at Big Spring. The soil surface was flat and the roughness and residue levels did not change for several weeks. There were 30 rainfall events that wet the soil surface and 33 wind erosion events. APPENDICES J-2 through J-6 are the monthly weather data summaries for Big Spring for the 1990 season. The measured erosion was 18.6 kg/m^2 and estimated erosion with RWEQ97 was 17.1 kg/m^2. Without corrections for soil wetness (zero rain days) the estimated erosion was 20.0 kg/m^2.

3.2.3.2 **Snow cover (*SD*)**

The snow cover factor is equal to 1 minus the probability of snow depth greater than 25.4 mm. Monthly snow probability values are in the weather data files. If the soil is covered with snow, there is no erosion and the SD = 0. If 50% of the time in a month the soil is covered with snow, the SD = 0.5 and the WF is 50% the normal WF without snow.

3.3 SOILS EQUATIONS

3.3.1 Soil erodible fraction (*EF*)

The erodible fraction is that fraction of the surface 25 mm of soil that is smaller than 0.84 mm in diameter as determined by a standard compact rotary sieve (Chepil, 1962). The preferred method for determining *EF* is to collect and sieve a sample of the surface soil each month for three years. From a soil sieving data base, the highest value for *EF* during a year for each site was correlated with basic soil physical and chemical properties (Fryrear *et al.*, 1994). The formula developed from this study follows.

$$EF = \frac{29.09 + 0.31Sa + 0.17Si + 0.33\,Sa/Cl - 2.59OM - 0.95CaCO_3}{100} \qquad \textbf{[16]}$$

$$r^2 = 0.67$$

where

Sa	=	sand content, %	(5.5 to 93.6)
Si	=	silt content, %	(0.5 to 69.5)
Sa/Cl	=	sand to clay ratio	(1.2 to 53.0)
OM	=	organic matter, %	(0.18 to 4.79)
$CaCO_3$	=	calcium carbonate, %	(0.0 to 25.2).

The range of values in the data set are given in parenthesis above. Equation **[16]** has not been verified for values outside these limits.

3.3.2 Soil crust factor (*SCF*)

When raindrops impact the soil surface, there is a redistribution of soil particles and a formation of surface crust. The resulting soil surface can be extremely hard or very fragile and may decrease or increase wind erosion potential (Zobeck, 1991). For sandy soils or for soils with a significant percentage of sand, a layer of loose, erodible sand grains forms on the top of the smooth crust. These sand grains are easily eroded by wind because the rain-impacted soil surface is aerodynamically smoother than the cloddy surface before the rain.

In WEQ a fully crusted soil was assumed to have soil losses 1/6 of the noncrusted soil (Woodruff and Siddoway, 1965). This may be reasonable for silt loam soils but does not represent sandy loam soils.

The *SCF* equation in RWEQ (equation **[17]**) was developed by regressing *SCF*, as determined from the abrasion coefficient, on clay and organic matter content. This *SCF* was developed using laboratory wind tunnel tests on resistance of soil aggregates and crusts to windblown sand (Hagen *et al.*, 1992)(Table 3.3.2).

$$SCF = \frac{1}{1 + 0.0066(Cl)^2 + 0.021(OM)^2} \qquad \textbf{[17]}$$

where

Cl	=	clay content, %	(5.0 to 39.3)
OM	=	organic matter, %	(0.32 to 4.74).

The limits of equation **[17]** are in parentheses. The coefficient of variation between *SCF* from the abrasive coefficient test and the *SCF* computed using equation **[17]** is 0.887.

In RWEQ, when accumulated rain equals or exceeds 12 mm since the last tillage operation, a soil crust factor is computed. Whenever clay content is less than 5% or immediately after a tillage operation when there is no surface crust, the *SCF* is set at one. The effects of *SCF* are evident in mass transport and critical field length equations.

Table 3.3.2. Development of empirical coefficients for SCF (equation **[17]**) using abrasive coefficient data base of Hagen *et al.* (1992).

Soil Series	Clay %	Organic Matter %	Abrasion Coefficient	Normalized Abrasion Factor*	SCF from Eq. **[17]**
Carr sandy loam	5.5	0.86	0.0732	1.000	0.823
Acuff fine sandy loam	12.2	2.53	0.0483	0.660	0.472
Alliance fine silty loam	21.1	0.56	0.0106	0.145	0.253
Amarillo fine sandy loam	11.3	0.47	0.0346	0.473	0.541
Amarillo fine sandy loam	14.8	0.34	0.0255	0.348	0.408
Amarillo loamy fine sand	8.5	4.74	0.0595	0.813	0.513
Barnes clay loam	31.6	1.10	0.0122	0.167	0.131
Cherry silt clay	26.0	2.25	0.0151	0.206	0.180
Drake fine sandy loam	11.2	0.32	0.0390	0.533	0.546
Gilford fine sandy loam	5.0	3.38	0.0523	0.714	0.712
Haynie silt loam	8.7	1.90	0.0372	0.508	0.635
Inavale loamy sand	5.9	0.80	0.0690	0.942	0.804
Kimo silty clay loam	36.0	2.20	0.0019	0.026	0.104
New Cambria silty clay	39.3	2.60	0.0016	0.022	0.088
Pullman clay loam	31.6	0.85	0.0086	0.117	0.131
Reading silt loam	23.6	2.30	0.0051	0.070	0.209
Reagan silt clay loam	29.4	2.02	0.0065	0.089	0.147

* Abrasion factor = Abrasion coefficient / 0.0732

3.4 RESIDUE and CROPS EQUATIONS

The quantity and orientation of crop residues in the field can have a significant impact on soil erosion by wind (Chepil, 1944; Englehorn *et al.*, 1952; Fryrear and Armburst, 1968; Siddoway *et al.*, 1965; Skidmore *et al.*, 1966). To quantify the effect of growing crops and residues on wind erosion, the fraction of the soil surface covered with nonerodible plant material, the plant silhouette from standing plant residues, and growing crop canopies are used (Bilbro and Fryrear, 1994). These factors were developed from laboratory wind tunnel studies.

3.4.1 Flat residues (SLR_f)

In RWEQ, the effect of flat residues (any lying on the soil surface) is described with a soil loss ratio coefficient (SLR_f) that was developed from numerous field and laboratory wind tunnel studies (APPENDIX G-1). In RWEQ, SLR_f is estimated from the decomposition routine or percent soil cover can be input if residues are added to a field.

Soil cover can be measured using the line transect method (Laflen *et al*., 1981)(APPENDIX G-1.1) or it can be estimated from a photograph or field observation. To convert SLR_f coefficients to percent cover APPENDIX G-1 can be used. From the tests to date, the diameter, density, or type of material is not as important as the percent of the soil surface that is covered (Bilbro and Fryrear, 1994).

$$SLR_f = e^{-0.0438(SC)} \qquad \textbf{[18]}$$

where

SLR_f = soil loss ratio coefficient for flat cover
SC = soil surface covered with flat residues, %.

If rock cover is present, it is added to the soil covered with *flat* residues. Rock cover is *not* decayed.

3.4.2 Standing residues (SLR_s)

Standing plant residues reduce the wind speed close to the soil surface. Laboratory wind tunnel studies on number, height, and diameter of standing material have been summarized into a soil loss ratio coefficient that reflects the silhouette of the standing material (SLR_s)(Bilbro and Fryrear, 1994). To determine the silhouette area, the height (harvest height), diameter, and number of standing stalks in a square meter area are used (APPENDIX B-1). The silhouette area value is related to the SLR_s with the following equation for a wind speed of 16 m/sec (Bilbro and Fryrear, 1994)(APPENDIX G-2).

$$SLR_s = e^{-0.0344\left(SA^{0.6413}\right)} \qquad \textbf{[19]}$$

where

SLR_s = soil loss ratio for plant silhouette

SA = silhouette area computed by multiplying the number of standing stalks in 1 m^2 times average diameter (cm) times stalk height (cm).

Average stalk height can be estimated from harvest height of the crop. If stalks are leaning after a tillage operation, the height of the stalk above the ground is used, not the total length of the stalk.

3.4.3 **Crop residue decomposition**

Decomposition of flat and standing residues is initialized by a harvest operation. Flat and standing crop residues are decayed with different coefficients. Research supports that temperature and number of rain-days can be used to compute the decomposition of plant residues. The parameters which should be regionally adjusted include economic yield level, plant population (plant or head number), crop height at harvest, and harvest height. These variables are used to estimate above ground residue and to partition residue mass into standing and flat pools (Schomberg and Steiner, 1997; Steiner *et al.*, 1994).

The percent soil cover (SC) is calculated using the flat residue mass (M_f) and the mass cover conversion factor (mcf)(APPENDIX B-1).

$$SC = 100\left(1 - e^{mcf\,(M_f)}\right) \quad \textbf{[20]}$$

Decomposition coefficients are available for 10 crops and studies are underway to expand the data base.

3.4.4 **Crop canopy (*SLR*$_c$)**

Emerging crop seedlings and subsequent larger plants provide a partial canopy cover over the soil. Field data have been collected to describe the canopy of several crops. From these data, a curve was developed for each crop that predicts the soil loss ratio due to canopy effects (SLR_c)(APPENDIX G-3).

The crop canopy coefficient is not used unless green living plants are in the field. The development of a crop canopy is initiated with a planting operation in the management input file. It is possible for ground cover, plant silhouette, and crop canopy to be present in the field at the same time.

To convert the influence of crop canopy to soil loss ratio the following equation is used

$$SLR_c = e^{-5.614\left(cc^{0.7366}\right)} \quad \textbf{[21]}$$

where

SLR_c = soil loss ratio for growing crop canopy
cc = fraction of soil surface covered with crop canopy.

Fractions of the land surface covered by growing crop canopies at various days after planting are presently available for six crops. The crop canopy data from RUSLE were used to develop crop canopy coefficients (APPENDIX B-2). The crop coefficients were developed for the first 60 days of crop growth, except for small grains which were for 75 days. The coefficients permit the computation of canopy cover every day or every 15 days. From this regression analysis two coefficients are developed for each crop. The equation form is

$$cc = e^{pgca + \left(\frac{pgcb}{P_d^{\,2}}\right)} \qquad \textbf{[22]}$$

where

cc	=	fraction of soil surface covered with crop canopy
P_d	=	days after planting
pgca	=	plant growth coefficient "a"
pgcb	=	plant growth coefficient "b".

For example, the file for soybeans is named "G_SOYBEA". The two values in the soybean growing crop file are bolded below.

Plant Growth Coefficient	"a", pgca	**0.542**
Plant Growth Coefficient	"b", pgcb	**-3162.92**

3.5 TILLAGE ROUGHNESS

Tillage roughness may be oriented (ridges and furrows) and/or random (soil clods). Roughness is formed by tillage and degraded by weather. Tillage operations modify the soil surface roughness and flatten and bury crop residues (Nelson *et al.*, 1993). The surface roughness immediately after tillage depends on the implement used, residue levels, soil texture, soil moisture, and the previous operation.

Successful estimates of soil erosion require accurate descriptions of soil surface conditions produced by tillage operations and degraded by weather. For example, Chepil and Woodruff (1954) estimated soil erosion for a smooth soil could be reduced from 5.6 to 0.056 kg/m^2 with a single listing operation. In RWEQ the effect of roughness generated by tillage operations on soil erosion is input with the relationships developed by Fryrear (1984) and Saleh and Fryrear (1997).

3.5.1 Soil roughness

Soil surface roughness due to aggregates can be measured and expressed using a pin meter (Potter and Zobeck, 1990), the chain method (Saleh, 1993) or the Allmaras *et al.* (1966) random roughness index (*RR*). The following equation is used in RWEQ to convert *RR* in inches to chain random roughness (C_{rr})(Saleh, 1997).

$$C_{rr} = 17.46\, RR^{0.738} \quad \textbf{[23]}$$

Soil ridge roughness (Zingg and Woodruff, 1951) is computed with the equation:

$$K_r = 4\,\frac{(RH)^2}{RS} \quad \textbf{[24]}$$

where

K_r = soil ridge roughness, cm
RH = ridge height, cm
RS = ridge spacing, cm.

Soil ridge roughness and random roughness parallel to the dominant wind direction are expressed in the single soil roughness factor (*K'*). When the wind is parallel to the soil ridges, *K'* includes only the random roughness (Allmaras *et al.*,1966; Zobeck and Onstad, 1987); when the wind is perpendicular to the soil ridges, *K'* includes both ridge (K_r) and random roughness (C_{rr}). In RWEQ *K'* is calculated as follows:

$$K' = e^{(1.86\,K_{rmod} - 2.41\,K_{rmod}^{\;0.934} - 0.124\,C_{rr})} \quad \textbf{[25]}$$

where

K_{rmod} = $R_c\,(K_r)$ which corrects K_r for wind angle when
R_c = rotational coefficient calculated in equation **[26]**.

This rotational coefficient is necessary if the wind is at an angle to the ridges. In RWEQ the following equation makes an adjustment for roughness based on the attack angle of the wind (Saleh, 1994).

$$R_c = 1 - 0.00032\,A - 0.000349\,A^2 + 0.00000258\,A^3 \quad \textbf{[26]}$$

where

A = wind angle (0 if perpendicular, 90 if parallel), degrees.

3.5.2 **Degradation of soil roughness**

Zobeck and Popham (1997) computed degradation of soil aggregate roughness for an Acuff sandy clay loam using rainfall amount and intensity. However for RWEQ, the degradation of ridges and aggregates needs to be computed for *any* soil texture. Saleh (APPENDIX O) developed equations **[27]** and **[28]** to use percent clay, cumulative rainfall, and cumulative storm erosivity index to compute degradation of ridges for any soil texture.

$$ORR = e^{\left[DF\left(-0.025\left(CUMEI^{0.31}\right)-0.0085\left(CUMR^{0.567}\right)\right)\right]} \qquad [27]$$

$$r^2 = 0.99, \quad P < 0.001$$

where

ORR	=	ratio of K_r after rainfall to K_r before rainfall
CUMEI	=	cumulative storm erosivity index, MJ-mm/ha-h
CUMR	=	cumulative rainfall, mm
DF	=	decay factor

where the decay factor is computed as

$$DF = e^{\left(0.943-0.07Cl+0.0011\left(Cl^2\right)-0.674OM+0.12\left(OM^2\right)\right)} \quad . \qquad [28]$$

In RWEQ, equation **[29]** is used to degrade aggregate or random roughness.

$$RRR = e^{\left[DF\left(-0.0009CUMEI-0.0007CUMR\right)\right]} \qquad [29]$$

$$r^2 = 0.95, \quad P < 0.001$$

where

RRR = ratio of C_{rr} after rainfall to C_{rr} before rainfall.

3.6 WINDBARRIERS/SHELTERBELTS

Before RWEQ, windbarriers were assumed to protect the downwind field for a distance equal to ten times the height of the barrier. The method for describing the effect of windbarriers on leeward wind speeds was developed from analysis of published results. Dr. Bilbro assembled published data on reduction patterns as a function of wind speed, optical density, and distance downwind (Sturrock, 1969, 1972). The data from Sturrock's publications are listed in Table 3.6.1. (It was assumed that when optical density = 0, PUV at the downwind H's was 100.)

Many equations can be used to describe the relationships. In RWEQ the equation is

$$PUV = 100 e^{-(OD)^{0.423}(DD)^{-1.098}} \qquad [30]$$

$$r^2 = 0.86$$

where

PUV	=	percent of upwind velocity
OD	=	optical density (range 28 to 100%)
DD	=	distance downwind in barrier heights, H.

The limitations are no *PUV* greater than 100 and protected distance no greater than 30 times the barrier height.

Table 3.6.1. Wind reduction (*PUV*) data used to develop the wind barrier model from optical density (*OD*) and downwind distance (*DD*). Data are from Sturrock (1969, 1972).

Optical Density	Downwind Distance	*PUV*	Optical Density	Downwind Distance	*PUV*	Optical Density	Downwind Distance	*PUV*
28	5	57	63	15	63	74	10	56
28	10	75	63	15	66	74	10	65
28	15	90	63	20	73	74	15	76
28	20	96	63	20	71	74	15	78
28	25	98	63	25	75	74	20	81
28	30	99	63	30	76	74	20	86
33	5	38	65	5	48	74	25	87
33	10	62	65	10	57	74	25	89
33	15	76	65	15	75	74	30	92
33	20	78	66	5	27	74	30	91
49	5	58	66	10	59	88	5	27
49	10	70	66	15	77	88	10	64
49	15	88	66	20	86	88	15	78
49	20	91	66	25	87	88	20	82
49	25	92	66	30	91	91	5	33
49	30	93	67	5	49	91	10	42
52	5	55	67	10	59	91	15	64
52	10	54	67	15	73	91	20	78
52	15	63	67	20	84	91	25	87
52	20	70	67	25	89	91	30	93
52	25	75	68	5	33	100	5	45
55	5	60	68	10	40	100	5	35
55	10	66	68	15	68	100	5	40
55	15	79	68	20	76	100	10	53
55	20	88	68	25	82	100	10	60
55	25	90	71	5	30	100	10	50
55	30	93	71	10	54	100	15	75
56	5	28	71	15	72	100	15	70
56	10	57	71	20	82	100	15	66
56	15	75	72	5	38	100	20	81
56	20	85	72	10	49	100	20	80
56	25	90	72	15	72	100	20	84
56	30	93	72	20	78	100	25	84
63	5	25	72	25	85	100	25	88
63	5	29	72	30	90	100	25	86
63	10	43	74	5	30	100	30	91
63	10	55	74	5	43	100	30	93

3.7 **HILLS**

Hill slope gradient and slope length are used to express the effect of hills on wind speeds. RWEQ assumes that the hill extends perpendicular to the wind and that the upwind toe of the hill is at the upwind edge of the field.

The equation to describe the wind speed over a hill was adapted from Queney (1948). His equation was designed to estimate wind speed over low, gently sloping, smooth-profiled, narrow mountains where the effects of the earth's rotation and tropopause are negligible and the height does not exceed 10% of the base (Figure 3.7.1). Equation **[31]** computes the 2-meter- high wind speed at various points along the slope.

$$U(x) = U\left[1 + \left[\frac{H_H \times a}{a^2 + (x')^2} * \frac{a^2 - (x')^2}{a^2 + (x')^2}\right]\right] \quad \textbf{[31]}$$

where

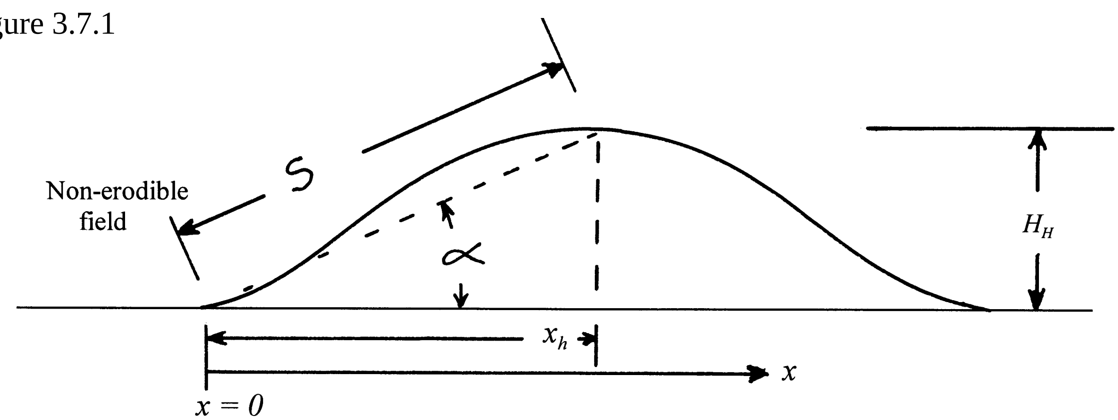
$U(x)$	=	2-meter wind speed at distance x from upwind edge of field, m/sec
U	=	open wind speed for flat surface, m/sec
H_H	=	height of hill, meters or $H_H = S \div sin$
a	=	characteristic ½ width of hill which is ½ distance from toe of hill to peak, meters or $a = cos\ (½\ S)$
x'	=	horizontal distance from center of hill, meters or $x' = x - x_h$

where

α	=	angle of slope, degrees
S	=	slope length, meters
G	=	slope gradient or $G = tan\ = H_H \div x_h$
x	=	distance from upwind edge of field, meters
x_h	=	distance from edge of field to center of hill, meters.

In RWEQ97 a is assumed equal to x_h. The slope length (S) and slope gradient (G) are inputs to describe the hill.

Figure 3.7.1



3.8 **COMPUTING MAXIMUM TRANSPORT CAPACITY *(Q_{max})***

To estimate transport mass for any field the coefficients (Q_{max} and *s*) must be computed from known field conditions.

The measured Q_{max} for individual events in instrumented fields was determined from 9 transport mass (total airborne mass from soil surface to height of 2 meters) and field length data values using least square analysis procedure with equation **[6]**. For single events *EF*, *SCF*, *K*, *COG*, *SW* and *SD* are assumed constant. Equation **[32]** was obtained by regressing measured input of *WF*, *EF*, *SCF*, *K*, and *COG* from instrumented field sites with the measured Q_{max} value from single events (Table 3.8.1).

$$Q_{max} = 109.8(WF \times EF \times SCF \times COG) \qquad \textbf{[32]}$$

$$r^2 = 0.84$$

where

Q_{max}	=	maximum transport capacity, kg/meter-width
EF	=	erodible fraction
SCF	=	soil crust factor
K'	=	soil roughness factor
COG	=	combined crop factors ($SLR_f \times SLR_s \times SLR_c$)
WF	=	weather factor, kg/m.

3.9 **COMPUTING CRITICAL FIELD LENGTH *(s)***

The capacity of the wind to erode and transport soil limits the increase in transport mass when field length is greater than the critical field length, *s*. Critical field lengths for individual events were computed with equation **[6]** using least square analysis of the transport mass field length data (Table 3.8.1).

The regression of computed field length *s* and wind, soil, and crop parameters gives

$$s = 150.71(WF \times EF \times SCF \times K' \times COG)^{-0.3711} \qquad \textbf{[33]}$$

$$r^2 = 0.46 \quad .$$

Table 3.8.1 Date of erosion event, wind factor (*WF*), soil erodible fraction (*EF*), soil crust factor (*SCF*), soil roughness (*K'*), flat and standing residues (*COG*), measured soil loss (*MSL*), estimated soil loss (*ESL*), maximum transport capacity (Q_{max}), and critical field length (*s*) for selected erosion events. Sites are coded Big Spring, Texas (BS); Mabton, Washington (MW); Elkhart, Kansas (EK); Kennett, Missouri (KM); and Eads, Colorado (EC).

Site	Date	Factors					Soil Loss		Q_{max}	*s*
		WF	*EF*	*SCF*	*K'*	*COG*	*MSL*	*ESL*		
							kg/m^2		kg/m	m
BS	1-27-90*	2.3	.64	.77	.95	.90	.55	.57	112	123
BS	1-29-90	2.8	.64	.77	.95	.90	.80	.70	133	88
BS	2-08-90	0.6	.64	.77	.95	.90	.15	.15	96	289
BS	3-06-90	2.8	.64	.77	.95	.90	.93	.70	226	149
BS	3-29-93**	3.6	.77	.77	1.00	.96	2.46	1.21	402	84
MW	4-02-91	8.4	.79	.91	.82	.43	1.14	1.25	168	43
EK	3-09-92	41.9	.70	.65	.91	.65	8.03	6.64	1430	98
KM	3-13-93	15.3	.85	.90	.85	1.00	4.05	5.86	751	109
EC	3-12-91	179.9	.26	.21	.80	.48	2.14	2.22	648	179

* Includes January 27th and 28th, 1990 wind data.
** Includes March 28th and 29th, 1993 wind data.

3.10 DEFINITION OF SYMBOLS

α	=	angle of slope, degrees
ρ	=	air density, kg/m^3
a	=	characteristic ½ width of hill, meters
A	=	wind angle (0 if perpendicular, 90 if parallel), degrees
$b(x)$	=	field length scale, meters
$CaCO_3$	=	calcium carbonate, %
cc	=	fraction of soil surface covered with crop canopy
Cl	=	clay content, %
COG	=	combined crop factors ($SLR_f \times SLR_s \times SLR_c$)
C_{rr}	=	chain random roughness
$CUMEI$	=	cumulative storm erosivity index, MJ-mm/ha-h
$CUMR$	=	cumulative rainfall, mm
DD	=	distance downwind in barrier heights
DF	=	decay factor
DT	=	average temperature, degrees centigrade
EF	=	erodible fraction (portion less than 0.84 mm in diameter)
ESL	=	estimated soil loss, kg/m^2
ET_p	=	potential relative evapotranspiration, mm
G	=	slope gradient
g	=	acceleration due to gravity, m/sec/sec
H	=	barrier height
H_H	=	height of hill, meters
K'	=	soil roughness factor
K_r	=	soil ridge roughness, cm
K_{rmod}	=	soil ridge roughness corrected for wind angle, cm
mcf	=	mass cover conversion factor
M_f	=	surface flat residue, kg/ha
MSL	=	measured soil loss, kg/m^2
N	=	number of wind speed observations
N_d	=	number of days
OD	=	optical density, %
OM	=	organic matter, %
ORR	=	ratio of K_r after rainfall to K_r before rainfall
$pgca$	=	plant growth coefficient "a"
$pgcb$	=	plant growth coefficient "b"
P_d	=	days after planting
PUV	=	percent of upwind velocity
Q	=	transport mass, kg/meter-width
$Q_{max}(x)$	=	maximum transport, kg/meter-width
$Q(x)$	=	mass transport at downwind distance x, kg/meter-width
R_c	=	rotational coefficient
R_d	=	number of rainfall and/or irrigation days

R+I	=	rainfall and irrigation, mm
RH	=	ridge height, cm
RR	=	random roughness index, inches
RRR	=	ratio of C_{rr} after rainfall to C_{rr} before rainfall
RS	=	ridge spacing, cm
s	=	critical field length where *Q(s)* is equal to 63.2% of Q_{max}
S	=	slope length, meters
Sa	=	sand content, %
SA	=	silhouette area per unit soil area, cm^2/m^2
Sa/Cl	=	sand to clay ratio
SC	=	soil surface covered with flat residues, %
SCF	=	soil crust factor
SD	=	snow cover factor
Si	=	silt content, %
SLR_c	=	soil loss ratio for growing crop canopy
SLR_f	=	soil loss ratio for flat cover
SLR_s	=	soil loss ratio for plant silhouette
SR	=	solar radiation, cal/cm^2
$S_r(x)$	=	surface retention coefficient
SW	=	soil wetness factor
U	=	open wind speed for flat surface, m/sec
U_2	=	wind speed at 2 meters, m/sec
U_t	=	threshold wind speed at 2 meters, assumed 5 m/sec
U(x)	=	2-meter wind speed at *x* distance from upwind edge of field, m/sec
W	=	wind value, $(m/sec)^3$
Wf	=	wind factor, $(m/sec)^3$
WF	=	weather factor, kg/m
x	=	distance from upwind edge of field, meters
x_h	=	distance from edge of field to center of hill, meters
x'	=	horizontal distance from center of hill, meters