6.0   SITE EROSION POTENTIAL AND EVALUATION

6.1   General

The foremost challenge facing the designer is to correctly assess the erosion potential resulting from the construction activities. The site erosion potential is an estimate of the quantity of soil that could be removed from the construction site due to erosion and transportation by unconcentrated surface water flow.   With certain modifications, established soil loss evaluation methods used in agricultural practice can be reasonably applied to the highway construction practice. The estimates produced by using these methods should be supplemented with judgement and experience so that the site erosion potential assessment is appropriate for the construction site.

6.2   Revised Universal Soil Loss Equation (RUSLE)

A number of methods to assess site erosion potential have been developed. Two approaches are in current practice for estimating highway construction site erosion potential. One is an empirical method based mainly on experience, the other is the Revised Universal Soil Loss Equation (RUSLE) which is an update of the Universal Soil Loss Equation (USLE). RUSLE's calculations are computerized as are the databases which include information on soil erodibility (K) and climate (R) data for all major soils and cities across the United States. As this program was developed in the United States no data is available for Canadian locations. The Revised Universal Soil Loss Equation for Application in Canada (RUSLE–FAC) (Wall et al, 1997) is a revision of RUSLE, modified for use in Canada and is not available in the form of a computerized software and data package.

The upgraded version of the RUSLE has been developed and is known as RUSLE Version 2, (RUSLE2). It uses the same input parameters as RUSLE to provide erosion and sediment delivery estimates. The new aspects of RUSLE2 are:

- Most factors and relationships have been revised.

- More current climate data.

- Model calculates soil loss for every day of the year. The average annual soil loss is the sum of all daily values.

- Windows based graphical user interface which allows the user flexibility in the types of situations to be represented.

RUSLE2 does not contain data for Canadian locations.

Additional information about RUSLE2 can be found at http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Index.htm

USLE/RUSLE only predicts the amount of soil loss that results from sheet or rill erosion on a single slope and does not account for additional soil losses that might occur from gully, wind or tillage erosion nor does it calculate sediment yield.

For the remainder of this manual, references and examples will focus on RUSLE-FAC, which will be simply referred to as "RUSLE".

The RUSLE formula is as follows:

$$A = R \times K \times LS \times C \times P \qquad \text{(Equation 6.1)}$$

Where: A = Annual soil loss (tonnes ha^{-1} year^{-1})

R = Rainfall factor (MJ mm ha^{-1} hour^{-1} year^{-1})

K = Soil erodibility factor (tonne hour MJ^{-1} mm^{-1})

LS = L and S are the slope length and steepness factors, respectively (dimensionless)

C = Vegetation and Management Factor (dimensionless)

P = Support Practice Factor (dimensionless)

Supporting information to assist in the selection of these factors is presented in Appendix B.

6.2.1 Rainfall Factor, R

The rainfall factor, R, is a measure of the total annual erosive rainfall for a specific location, combined with the distribution of erosive rainfall throughout the year. The high energy thunderstorms of the summer months are generally regarded to be the most potentially erosive events in most areas of Alberta.

The rainfall factor is the average annual sum of the products of the two variables most critical to a storm's erosivity:

- Volume of rainfall and runoff (E); and

- Prolonged-peak rates of detachment and runoff (I) (Wischmeier and Smith, 1978).

EI is the total kinetic energy of a storm multiplied by the maximum 30-minute intensity.

R is estimated through the use of the following three primary methods:

1. Measured rainstorm EI values. This method is suitable if 22 or more years of rainfall intensity data is available (Wischmeier and Smith, 1978).

2. Equations which rely on an empirical relationship between R and the one-in-two year, 6 hour storm, (Ateshian, 1974; Madramootoo, 1988; Wall et al., 1983).

3. Hourly precipitation records, where available, to predict R (Wigham and Stolte, 1986).

The aforementioned three methods used to estimate R have been used to produce the following reference materials for Canadian conditions:

- Isoerodent maps which indicate annual R values for an area and can be used to calculate average annual soil losses;

- Monthly distribution of R which indicates the proportion of annual erosive rainfall that falls during each month; and

- Mean annual rainfall on frozen soil maps, which may indicate areas where rain falling on frozen soil could pose an erosion risk.

It is typical in roadway construction to re-establish grass vegetation as soon as practicable after grading has been complete. In many cases, the contractual requirements necessitate that seeding and fertilizing be quickly undertaken by the contractor, preferably as soon as cut and fill slope surfaces are completed. Through this activity, the sediment yield from a site can be reduced from that anticipated for an entire year of exposure. In these cases, it is more appropriate to assign a monthly distribution of the soil loss over a time period where the soils are anticipated to be exposed. Therefore, an R value can be estimated for the entire year (R_t) or for a portion or season of the year (R_s). The estimation of R_t and R_s is discussed in the following paragraphs.

Estimation of R_t

The following procedure may be followed to estimate a value of R_t:

1. Locate the area of interest in Figure B-1, Appendix B, Isoerodent map showing R_t values (yearly) for the Prairie Region. Extrapolate point or area relative to R_t factor contours.

2. Similarly, locate the area of interest in Figure B-3, Appendix B, adjustment for winter conditions, R_s for the Prairie Region.

3. R values for spring to fall are presented in Figure B-2, Appendix B for non-winter conditions.

Estimation of R_s

The following procedure may be followed to estimate a value of R_s:

- Determine time of interest;

- Select the monthly distribution from climatic station closest to the area of interest from Figure B-4 and Table B-1, Appendix B;

- Add the monthly values for the time of interest and determine a percentage of R_t for the construction period; and

- Multiply the value by the total annual R_t value to obtain the seasonal R value.

6.2.2   Soil Erodibility Factor, K

6.2.2.1 Estimation of K

The K factor is a quantitative measure of a soil's inherent susceptibility to erosion. Generally, on the basis of soil characteristics alone, soils with a high percent content of silt and very fine sand particles, as well as a low fibrous organic matter content, will be most erodible. A preliminary assessment of soil erodibility has been presented in Figure 4.2. K values estimated using the methods detailed herein are appropriate for soils encountered in agricultural practice. As such, a soil erodibility adjustment factor ($Ø_K$) is proposed to permit application of the estimated K values to highway construction sites and is discussed in Section 6.2.2.2.

A K value can be calculated for a specific soil, using the following equation (Wischmeier and Smith, 1978).

$$K = [2.1 \times 10^{-4}(12-a)M^{1.14} + 3.25(b-2)+2.5(c-3)]/100 \qquad \text{(Equation 6.2)}$$

Where: M   =   (% silt + very fine sand) x (100 - % clay)

   a   =   % organic matter

   b   =   the soil structure code used in soil classification (Figure B-6), and

   c   =   the profile permeability class (Figure B-7)

The input parameters for the aforementioned equation are routinely characterized through standard soil profile descriptions and laboratory analyses. These parameters are listed as follows:

- % silt plus very fine sand (soil particle sizes between 0.05 and 0.10 mm);

- % sand greater than 0.10 mm;

- Soil structure;

- Permeability; and

- Organic matter content.

Of these variables, organic matter content can usually be assumed to be zero in road embankments or deep cuts.

The soil erodibility nomograph (Figure B-5, Appendix B) provides a graphical solution for determining a soil's K value, and can be used if the percent sand and organic matter fractions in a particular soil are known.

The soil erodibility potential is low for high plasticity clayey soil and coarse to medium grained granular soils; therefore, gradation analysis including hydrometer testing of these soils would not usually be required for an erodibility assessment. The soil erodibility can be high to medium for low to non-plastic soil and soil with significant amounts of silt and fine sand. Therefore gradation analysis including hydrometer testing is required.

Where the soil fractions are not known, K factors have been estimated for a number of surface textures and for approximate organic matter content. Major textural groups and their corresponding K values are listed (Table B-2, Appendix B).

6.2.2.2   Soil Erodibility Adjustment Factor ($\varnothing_K$)

It should be noted that the soil erodibility factor (K) has been developed for an agricultural setting. It is important to recognize that the level of consolidation and/or compaction of soils encountered on cut and fill areas in a highway construction setting is usually much greater than that encountered in an agricultural setting. Cutslopes in highway construction will consist of consolidated material and fill slopes will have undergone significant compaction effort and moisture conditioning. For fill embankments, compaction energy was exerted on the soils at thin lifts with moisture conditioning (to moisten or dry the soil to an optimum moisture content) to achieve a maximum dry density (Standard Proctor Density). Most highway fills are constructed with mineral soils with minimal organic content. This situation differs greatly from an agriculture setting where soils have been machine agitated to produce loose conditions that promote plant growth. Furthermore, a compact soil in an agricultural setting is not

the same as a well compacted or consolidated soil on a highway construction site. However, despite the compaction efforts to improve soil structure strength in a highway construction setting, silty and low plasticity fine-grained soils are generally considered as highly erodible.

Based on the aforementioned differences in the erodibility for soils encountered in highway construction and agricultural settings, the soil encountered in a highway should have a lower erodibility rating. Thus, a modification factor ($\emptyset_K$) should be applied to lower the K factor determined as part of the RUSLE approach to estimating soil loss. Based on engineering judgement, a range of 0.5 to 1.0 (with a suggested value of 0.8), is considered appropriate for $\emptyset_K$. However, the selection of $\emptyset_K$ is to be conducted at the discretion of the individual or firm engaged in estimating soil loss potential should be based on site conditions, experience and judgement. The suggested modification factor of 0.8 has been developed based on judgement for this document and represents a highway construction specific factor to be used in the RUSLE.

6.2.3 Topographic Factor, LS

6.2.3.1 Estimation of LS

The topographic factor, LS, is a combined factor that accounts for the effect of slope length (L) and slope steepness (S) factors on the site erosion potential. It adjusts the erosion prediction for a given slope length and slope angle to account for differences from slope conditions present at the standard erosion monitoring plot on which the USLE was based (LS=1 for slopes 22 m long with 9% grade).

For consolidated soil conditions, such as freshly prepared construction sites, with no to little vegetative cover, values of LS can be evaluated from the Topographic Factor Chart (Table B-3, Appendix B) for slope lengths varying from 2 to 300 m, and slopes ranging from 0.2 to 60%.

The upper end of a slope can be defined as the top of the slope, or the divide down a ridge in the field. The lower end of a slope can be located by moving down the slope, perpendicular to the contours, until a broad area of deposition or a natural or constructed waterway is reached. Reducing either the length or steepness of a slope can reduce soil loss. However, reducing the steepness of a slope results in an increased slope length, thus the overall reduction of soil erosion may not be significant. Another way to reduce soil loss is to place intercepting berms along the contours. While this procedure will effectively reduce the cross-section to a series of simple slopes, costly earthworks may be required to establish the berms, which may not be justified unless fill material is readily acquired at a nearby location.

Estimation of the LS factor for uniform slopes and irregular slopes is discussed in the following paragraphs.

Uniform Slopes

The equation of the LS factor for a uniform slope is given as follows:

$$LS = (sl/22.13)^m \times S \qquad \text{(Equation 6.3)}$$

The slope factor "S" in RUSLE is given as follows (McCool et al., 1989):

$$S = 10.8\sin(\theta) + 0.03$$

when slope is <9%, length ≥ 5 m

$$S = 16.8\sin(\theta) + 0.50$$

when slope ≥ 9%, length ≥ 5 m

$$S = 3.0\sin(\theta)^{0.8} + 0.56$$

when length <5 m

Where: sl is the slope length of the site (m)

θ is the angle of the slope (in degrees)

m is a coefficient related to the ratio of rill to inter-rill erosion presented in Table B-4.

Irregular Slopes

The RUSLE provides a procedure for separating an irregular slope into segments. This procedure recognizes and adjusts for differences in the type of slope. For example:

- A **convex slope** will have a greater effective LS factor (i.e., a higher erosion estimate) than a uniform slope with the same average gradient; conversely

- A **concave slope** will generally have a lower effective erosion rate than a uniform slope of the same average gradient.

The irregular slope should be divided into a two to five segments that describe varying conditions down slope (i.e., soil type, practices, etc.).

Design examples illustrating evaluation of LS for irregular slope are presented in Appendix H as Examples H.4 and H.5.

6.2.3.2   Topographic Adjustment Factor ($\emptyset_{LS}$)

The RUSLE Topographic factor (LS) was developed for typical agricultural slopes with loosened surficial soils for most soil types of moderate to low erodibility. For highway construction applications, slopes are generally much steeper than this and the surficial soils are much denser. Typical slopes for a highway construction site in Alberta range from 3H:1V (33%) to 6H:1V (16%). Using RUSLE for a typical highway construction slope results in a relatively high LS value and subsequently high site erosion potential based on an agricultural setting. Although it is apparent that steeper slopes are more prone to erosion as a result of increased runoff velocities, the RUSLE classifications for site erosion potential are calibrated or standardized to a much lower slope gradient and therefore will require modification for use on highway construction sites.

In the agriculture practice of assessing the erodibility for slope with loose surficial soils, a gentle slope (9% slope, 22 m length) (Wischmeier and Smith, 1978) was chosen to calibrate a baseline value for slope erodibility factor (LS=1 in RUSLE) with other slope configurations of steepness and length. As a result, the LS factor is dependent on soil conditions, even though it is intended as a modifier for varying slope steepness. In

highway slopes with compacted soils, the same baseline slope configuration will yield a lower slope erodibility (LS) value due to the higher density in highway soils.

Based on the aforementioned differences between a highway construction and agricultural setting, the soils encountered in a highway setting should have a lower slope factor rating. Thus a Topographic Adjustment Factor ($\emptyset_{LS}$) is applied to lower the LS factor determined as part of the RUSLE approach to estimating soil loss. An $\emptyset_{LS}$ of 0.8 is suggested to address the inherent differences between highway construction and agricultural settings. However, the selection of $\emptyset_{LS}$ is to be conducted at the discretion of the individual or firm estimating soil loss potential based on site conditions, experience and judgement. The adjustment factor has been developed based on judgement for this document and represents a highway construction specific factor to be used in the RUSLE.

6.2.4 Vegetation and Management Factor, C

The C-factor is used to determine the relative effectiveness of soil management systems in terms of vegetation, crop cover and/or artificial protection cover (such as mulch, synthetic erosion protection matting) to effect preventing or reducing soil loss. For bare soil, C=1 can be used; for soil surface protected by mulch C=0.1 to 0.2 is common. Some construction site C-factor values are shown in Tables B-6a and B-6b (Appendix B).

6.2.5 Support Practice Factor, P (Practice Factor)

The P-factor is a measure of the effects of practices designed to modify the contouring flow pattern, grade, or direction of surface runoff and thus reduce the amount of erosion. Generally, a support practice is most effective when it causes eroded sediments to be deposited far upslope, very close to their source. In the absence of any support practices, P should be assumed to be 1.0 in the RUSLE formula. With the use of appropriate construction practice, the P factor can be reduced. For example, the practice of track roughening of bare slope (up/down slope) can reduce the P factor from 1.0 to 0.9. Estimation of P may well be the least accurate and most subject to error of the RUSLE factors, because of less data compared to other factors in the RUSLE formulation.

Some construction site P-factor values are provided in Table B-7, Appendix B.

The RUSLE brings in a mixture of empirical and process-based erosion technology to provide a better measure of the effect of land management on erosion rates. Values are based on hydrologic groups, slope, row grade, ridge height, and the 10-year single storm index values.

6.3 Empirical Method for Sediment Storage/Impoundment

The empirical method presents a general relationship between required storage capacity for sediment laden runoff from the construction site and the area of disturbed or exposed soil. This method should only be used for small drainage areas. Disturbed areas greater than 10 ha or long steep slopes must utilize better estimating procedures such as the RUSLE. It is important to note that consideration of various site specific factors that affect soil erosion rate are taken into account. Therefore, the empirical

method should be used with caution. The main advantage of the empirical approach is in its simplicity and ease of application.

Various jurisdictions utilize storage volume requirements ranging from 40 to 250 m³/ha. Sediment storage/impoundment ponds are normally designed at 1 m depth with a design volume varying from 150 m³/ha (minimum) to 250 m³/ha (recommended). It is assumed that vegetation will be established within one to two years of land disturbances taking place or that there will be at least one clean out of the sedimentation facilities per year. If neither is performed, a storage volume of 250 m³/ha (whenever possible) is recommended for sensitive areas and a minimum storage of 150 m³/ha will be required under conditions of restricted space availability. For design considerations, climate variability of different parts of the Province may affect or may require larger storage/impoundment capacity than mentioned above.

6.4 Examples for Estimating Site Erosion Potential

Examples using the RUSLE for determining the soil erosion potential are presented in Appendix H as Examples H.1, H.2 and H.3.

6.5 Site Evaluation

Once a site assessment has been completed, the information should be summarized to provide a complete summary evaluation of the slope and drainage conditions. The site evaluation is a critical step in the preparation of an erosion and sediment control plan and the summary information should be clearly indicated on drawings and supporting documents.

6.5.1 Slope Analysis Summary

As a minimum, a summary of the conditions of the slope to be exposed should be conducted to estimate the potential sediment loss from a site. Areas of exposure generally include all cut and fill slopes as well as large stockpiles and non-dugout borrow sources. It may be necessary to divide a slope area by drainage breaks and/or soil type. A representative value for each of the following parameters should be indicated on the erosion and sediment control plan drawings and supporting documents:

- Soil Type: Each distinctly separate soil type to be encountered should be delineated by area on the site plan. Where distinct soil type boundaries are not known or cannot be inferred, estimations of soil type areas are acceptable. Information from the site assessment will be helpful in defining the various soil types by area. Additional information gathered during construction can be used to update the soil type areas.

- RUSLE Factors: The RUSLE factors (R, K, LS, C, and P) as defined in Section 6.2 should be summarized for the general conditions of the site and for the specific conditions for each distinctly separate soil/ slope area to be encountered on the site.

- Site Erosion Potential / Hazard Class: Using the RUSLE factors, the soil erosion potential (tonnes/ha/year) should be estimated for each distinct area and period of anticipated construction activity. For the soil loss estimated for a particular site, the associated hazard classification can be obtained from Table 6.1.

- Special Sites: Any sites of special consideration should be indicated on the site plan, such as locations of potential slope instability, seepage, or borrow sources.

6.5.2   Drainage Analysis Summary

As a minimum, a summary of the drainage conditions to be encountered should be conducted and provided as information on the erosion and sediment control plan drawings and support documents.

- Drainage Catchment Areas: A topographic site plan of the construction site and contributing drainage catchment area(s) needs to be divided into smaller drainage areas based on topographic breaks in slope. Then, for each of the drainage areas identified, an estimate of size in hectares (ha) should be provided. Where the site has to be re-graded to final elevations, the direction of sediment-laden flow could change. Overland flow routes, for both initial and final site grade conditions, should be checked to ensure that the appropriate downstream environmental sensitivity has been evaluated.

- Watercourses: If not already shown on the topographic site plan, all watercourses should be identified and labelled. Watercourses consist of all areas of channelized flow (streams, creeks, ditches), as well as drainage collection features such as swamps, ponds and lakes. Design drawings should show all proposed ditchlines, catchments and crossings in addition to the natural drainage features. Information on watercourses should extend beyond the limits of the construction site. As a minimum, drainage connectivity should be established to the nearest body of sensitive water downstream of the construction site.

- Fisheries Classifications: Watercourses should be labelled with the appropriate fisheries classification.

- Floodplain Information: Where applicable, a clear definition of the floodplain limits should be shown on the drawings.

- Special Sites: Sites of special consideration should be indicated on the drawings.

6.5.3   Site Hazard Classification

Site hazard classification can be obtained from Table 6.1 below based on the estimate of site erosion potential (tonnes / ha / year).

Table 6.1: Site Hazard Classification (RUSLE-FAC *)

Site Erosion Potential (tonnes / ha / year)	Hazard Class
< 6	Very Low
6-11	Low
11-22	Moderate
22-33	High
> 33	Very High

Source: Wall et al, 1997*

6.5.4   Connectivity to Downstream Aquatic Resources

The location of the construction site with respect to downstream aquatic resources is a very important factor in preparing an erosion and sediment control plan. Establishing the connectivity of the construction site to downstream water supplies, flood control, fish habitat, navigation, and recreational activities can be conducted using information from the drainage analysis summary.

As far as this manual is concerned, the most negative, and therefore monitored, consequence from erosion and sedimentation is the degradation of water quality and more particularly the impact on fish habitat. The connectivity rating for each distinct segment on a construction site should be shown on the erosion and sediment control plan drawings.

The following table provides ratings based on connectivity to aquatic resources:

Table 6.2: Connectivity Rating to Aquatic Resources

Connectivity Rating	Criteria[1]
Direct	Any sediment from a construction site is transported directly downstream at a significant gradient (i.e., greater than 5%) to locations where it may result in adverse effects to water quality or aquatic resources.
Indirect	Sediment laden water from a construction site empties into a secondary watercourse (i.e., stream, ditch, swale) before connecting with any stream with water quality or aquatic resource values. The secondary watercourse must be a non-fish habitat watercourse, with a channel gradient no more than 5% for a minimum length of 100 m.
No Connectivity	For no connectivity, the sediment laden runoff flows into a non-significant[*] swamp or pond and sediment is trapped where water quality or aquatic resources are not a concern, or must terminate before connecting with any stream that has water quality or aquatic resource values.

[1]   Criteria adapted from British Columbia Ministry of Forests (2001).

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[*] Assessment of the significance of a swamp/pond should be undertaken by an environmental engineer/specialist.