3. LABORATORY AND FIELD TESTING FOR SALT

3.1 General

All natural gravels and water used for road and runway construction in Botswana should be tested for soluble salt content. Once it is established that soluble salts are present in significant concentration (e.g. >0.02% for materials, >2000 PPM for construction water), additional tests may be necessary to determine the main type(s) of salt present by ionic content analysis and/or X-Ray diffraction. Extra caution is required in obtaining and packing of samples for salt content tests as described below.

The broad procedures for salt content assessment and analysis to be followed are shown in the following Table:

Table 3.1 Salt Analysis Tests for materials and water in Botswana.

	Field Tests	Laboratory Stage 1	Laboratory Stage 2	Stage 3
Natural gravel	Electrical conductivity (2:1 soil paste)	● Electrical Conductivity (TMH - paste method) ● Total Dissolved Salts (TDS)	● Ionic composition Cl^-, SO_3 HCO_3, Na^+, K^+, Mg^{2+}	● X-Ray diffraction ● EPM ● Scanning Electron Microscopy
Subgrade soil	Electrical conductivity (2:1 soil paste)	● Electrical Conductivity (TMH - paste method) ● Total Dissolved Salts	- ditto -	- ditto -
Construction water	Mouth taste Electrical Conductivity pH	● Total Dissolved Salts ● pH ● Electrical Conductivity (EC)	- ditto -	- ditto - on residue
Applicability	Mandatory for all Projects (Mouth taste is optional)	Mandatory (Extent of EC testing depends on extent of field EC carried out).	Where no existing information on salt types exists. Essential for salt damage risk/design assessment.	Only necessary for detailed research purposes or if Stage 2 tests are not able to identify salt types

3.2 Soil and Water Sampling

Sampling for Salt Content Analysis

Extra caution is required when taking and handling water or soil samples for salt content analysis. This is required to take into account the variable distribution of salt in soil horizons and the potential consumption of salts in water by algae and bacteria.

3.2.1 Water Samples:

Water samples should be taken from near the surface of water sources to be used for construction.

Approximately 0.5 litres of water is normally adequate for most routine salt content analysis. Water samples should be taken and tightly sealed in a non-transparent glass or plastic bottle. Water samples exposed to the sun may attract algal growth. Such algae may feed on the salt and reduce the salt content prior to laboratory testing. All water samples should ideally not be stored for more than four weeks before testing.

When samples are taken from boreholes during drilling, it is important to ensure that samples are taken from each water strike level. The samples should be taken immediately the water is struck to avoid contamination from other aquifers. Electrical conductivity tests should be carried out on site using portable conductivity metres. Much of the groundwater present in western Botswana is ancient groundwater with variable levels of salinity.

3.2.2 Soil Samples:

Natural gravel from Borrow Pits

Approximately 50 to 100 gram samples are adequate for routine conductivity and TDS testing depending on grain size of selected gravels.

Samples used for salt testing should be taken from exploratory holes. A separate sample should be taken from the top 50mm of the upper most horizon encountered in the soil profile.

It would normally be adequate to assess the salinity level of a borrow pit on the basis of 3 to 8 full salt content tests (depending on size of borrow pit and local environment).

3.3 Field Salt Content Tests

3.3.1 Field Electrical Conductivity test

Electrical conductivity tests can be carried out very quickly in the field using the quick conductivity test method. This provides a good measure of salt content in water or soil which correlates well with more elaborate laboratory tests.

The methodology for field conductivity tests is relatively simple and is given in Appendix B. The equipment required can be carried in a small wooden case or brief case and comprises:

- Hand held conductivity metre,
- Porcelain conductivity cup,
- Stirrer, spatula, bottle of distilled water and a wash bottle.

Electrical conductivity may be related directly to salt damage potential because it measures only those salts which are soluble and can migrate in solution to the road surface where crystallisation occurs. E.C can therefore be used directly as an indicator of salt damage potential. As such, it can be used to assess whether preventative measures are required or not.

Water samples should be taken from near the surface of water sources to be used for construction.

Some aquifers with salinity levels exceeding that of sea water have been encountered along the Jwaneng - Ghanzi road. These are often overlain or underlain with fresh (non-saline) or brackish water aquifer.

Hand held conductivity metre, is an accurate and quick method to measure salt content.

E.C can also be correlated to TDS or Chloride ion content once the relationship between these are determined for a particular material/soil type or water body. The relationship between E.C and TDS for soils along the Nata to Maun road is TDS=0.04+0.16* E.C and this relationship is probably applicable for many of the saline soils in areas adjacent to Makgadikgadi Pan. In other areas of Botswana the relationship may vary due to the predominance of chlorides with less carbonate salts.

E.C test results should be expressed in millisiemens per centimetre (mS/cm) or Siemens per metre (S/M) at 25°C. A Siemen is the reciprocal of electrical resistance in ohms. The TDS and other salt content determinations are normally expressed as the % weight of the dry soil. In the case of water as milligrams per litre or parts per million (PPM).

3.3.2   Oral Testing (Taste)

A sweet taste similar to the taste of cooking salt will often indicate NaCl salt content of over 0.5%. A sharpe tangy taste may indicate the presence of carbonate salts or sulphates. Tongue tasting is particularly useful when trying to establish whether damage to bituminous surface is due to salt attack. A moistened finger touched to the underside of blistered or domed surfacings may be used.

3.3.3   Field Determination of TDS

The TDS of water samples may be determined in the field but it is usually better to do this under laboratory conditions because of the need for accurate weighting. A quick indication of levels of TDS can be obtained in the field by correlation with field EC, as described above, with upto 90% accuracy.

3.3.4   Field Chloride content determination

A rapid indication of PPM Chloride content of water samles may be obtained in the field with indicator strips or Tabs. These are chemically active strips which when dipped in water, will indicate the chloride content in a graduated column to a limited accuracy.

3.4   Laboratory Tests

3.4.1   Electrical Conductivity

Laboratory Electrical conductivity test may be determined either by the quick 2:1 soil paste method (Obika et at 1989) or the more lengthy saturated soil paste method. Details of the latter are given in TMH1 (1986) Method A21T. The 2:1 soil paste is based on agricultural practise and has been found to correlate well for engineering purposes. The methodology is given in Appendix B.

3.4.2   Total Dissolved Salts

The total dissolved salt (or sometimes termed total soluble salt, TSS) should be determined in accordance with SABS Method 849. For soils this involves shaking the ground soil sample with distilled water for a period of 24 hours and determining the mass of salt in a filtered aliquot by evaporating to complete dryness in an oven.
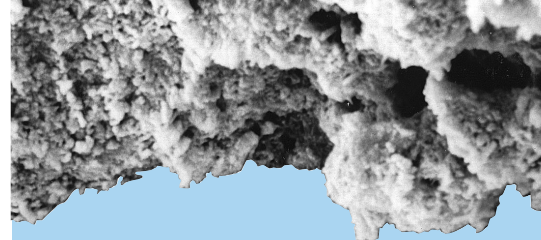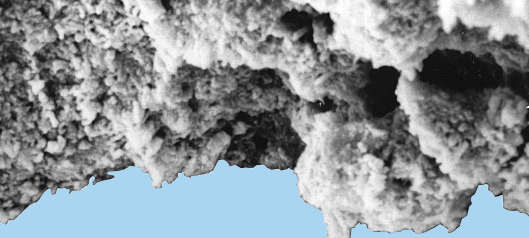

Caution is required when tasting soil and the mouth must be fully washed immediately after tasting.

Most field balance will only weigh to an accuracy of 0.2 g. and will therefore limit the accuracy.

Electrical conductivity test carried out at the CML.

TDS is expressed in milligrams per litre (or PPM) for water samples or percentage of the dry mass for soil samples.

Various methods are available for the determination of various Anions. Water soluble sulphates should be determined in accordance with THM 1 (1986) Method B17T. Chlorides can be determined by titration with barium sulphate and can be carried out in accordance with BS 812 Part 4 (1975).

Quantitative X-ray analysis is unlikely to be used for routine highway engineering purposes.

3.4.3   Ionic Composition

In order to determine the predominant types of salt present in a soil or water sample it is usually necessary to carry out an ionic content analysis. This information may be required particularly where there are no existing records of salt types.

Cations such as $Na+$ and $Mg++$ may be determined by flame photometry or atomic absorption methods using specialist apparatus.

A knowledge of the salt type provides an indication of the likely levels of salt content that will cause damage. Sulphate levels exceeding 0.05% TDS can cause damage whereas Chloride levels need to exceed 0.15% before damage occurs.

3.4.4   Mineralogic Analysis

The determination of the mineralogy of salts is not normally required for routine engineering purposes. The precise mineralogy of salts present in soils can be determined by qualitative X-Ray diffraction. Quantitaive X-Ray diffraction is more rigorous and costly but will also provide information on the quantity of salt present in a given soil sample.

3.5   Presentation of Salt Content Analysis Results

When presenting the results of salt content tests it is important to employ convention. Test results are frequently mis-interpreted due to use of differing terminology and units of measurement. For example 0.2% Cl- is quite different from 0.2% NaCl although both are frequently referred to as chloride. Sulphate content may be calculated as SO_3 or as SO_4. (to relate SO_3 to SO_4 multiply SO_3 by 1.2).
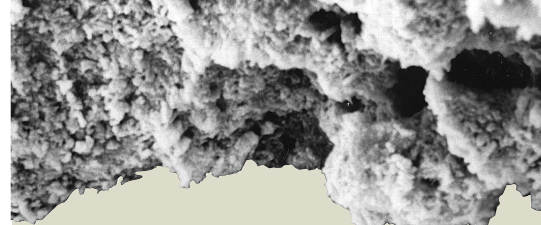
4. RISK EVALUATION IN SALINE ENVIRONMENTS

4.1 General

Salt damage risk evaluation is recommended whenever a bituminous surfacing is proposed for a pavement in Botswana. Clearly, the damage process is dependent on a complex interaction of many variables, but the proposed design method is based on two significant parameters, salt content and climate, which can be measured relatively easily. Further design parameters can be added as other variables can be linked to the damage process in qualitative terms. The procedure is illustrated in Figure 4 .1.
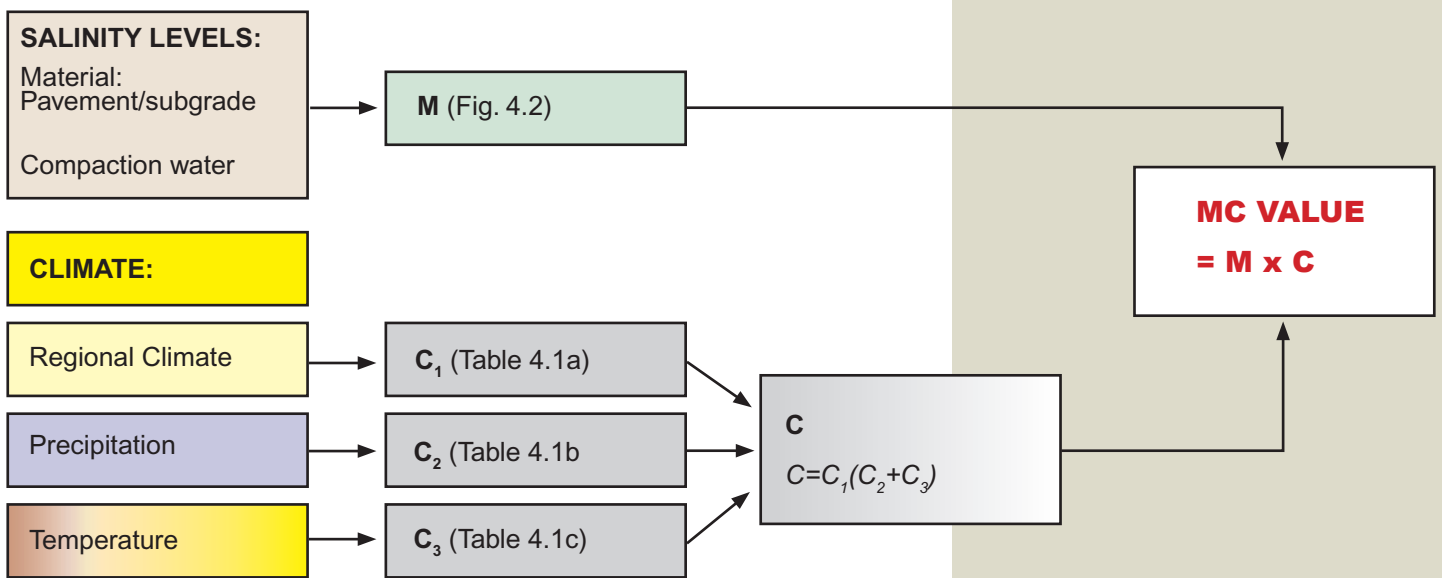

SALINITY LEVELS:
Material:
Pavement/subgrade

Compaction water

M (Fig. 4.2)

CLIMATE:

Regional Climate → C_1 (Table 4.1a)

Precipitation → C_2 (Table 4.1b)

Temperature → C_3 (Table 4.1c)

C
$C=C_1(C_2+C_3)$

MC VALUE
= M x C

Figure 4.1   Risk Analysis for salt damage to bituminous surfacings.

Firstly, a 'M' value is obtained by allocating scores depending on the salt levels in the pavement and subgrade, compaction water, and in some situations, ground water.

Secondly, a 'C' value is obtained by allocating scores to climatic conditions.

Thirdly, the values (M and C) are combined to provide an overall rating which indicates the damage risk for bituminous surfacings for the given project. A worked example is given in Appendix C.

4.2 Salinity Levels of Materials and Water

Salinity values are required for pavement and subgrade materials, imported and/or in-situ, and compaction and/or ground water. Methods for determining salt content contained in this guideline should be followed and it is important to adhere to these methods for consistency and comparability of results.

Salt measurement

In the first instance, total dissolved salts (TDS) will normally be measured, however it is useful to have some indication of the dominant salt type for more detailed design and construction control particularly if salt levels are significant.

The Electrical Conductivity (EC) should be measured. The correlation between the quick EC and the TDS measurements, for the Botswana field trials, where the TDS was measured according to the method given in BS 1377:Part 3, was: TDS = 0.04 + 0.16 EC.

A correlation coefficient of 0.9 was obtained for this relationship. All determinations were carried out on the minus 2 mm fraction of the samples, corresponding to about 75% by mass of the borrow pit material. The major proportion of the salt is contained in the fines.

The salt content of water and materials should each be determined separately. The risk assessment in this guideline takes into account the combined influence of each.

Obtaining Materials and Water rating ('M' Value)

Using the appropriate salt levels for materials and water determine the weighting value M from Figure 4.2. A M value of 10 should be adopted if the pavement or subgrade salinity exceeds 0.8% TDS irrespective of compaction water salinity.

Salt from compaction water is potentially more harmful than salt contained in the materials due to the ability of salt in water to rise more rapidly to the road surface.
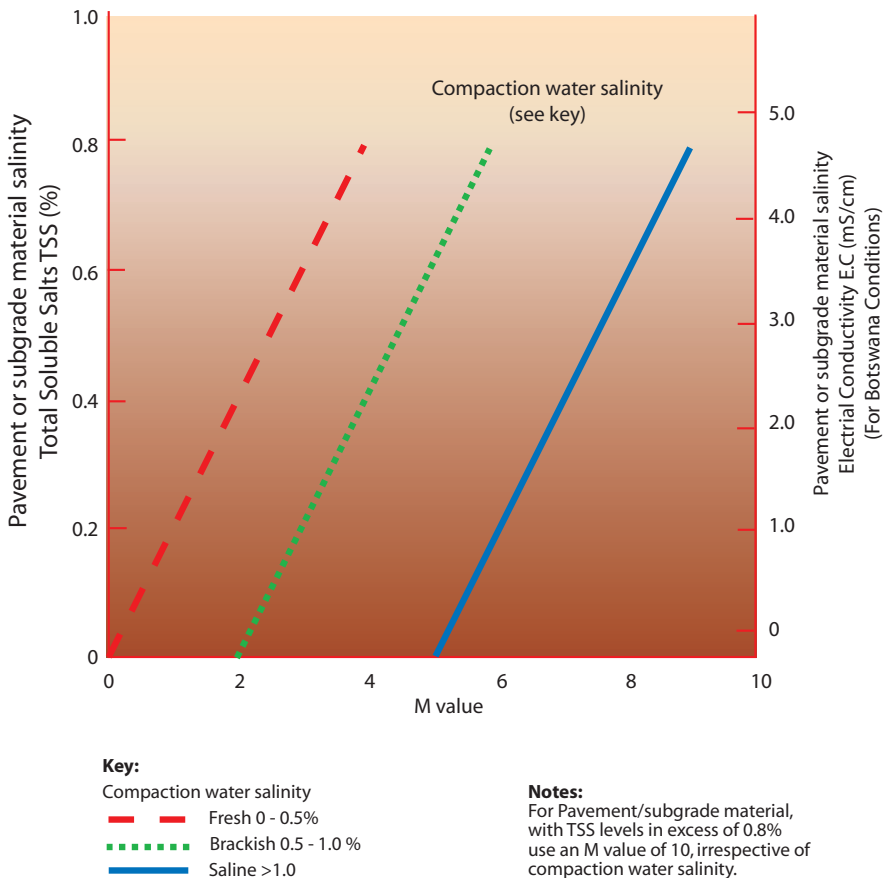

Key:
Compaction water salinity
- – – Fresh 0 - 0.5%
- ...... Brackish 0.5 - 1.0 %
- ——— Saline >1.0

Notes:
For Pavement/subgrade material, with TSS levels in excess of 0.8% use an M value of 10, irrespective of compaction water salinity.

Figure 4.2 Materials risk rating-salt damge to bituminous surfacings.

The salt content value to be used should be the maximum value obtained from the pavement or subgrade materials and may be measured either in terms of TDS, or EC if calibrated locally for the materials used. At this stage, the salt content of the bulk material or water is used (not the 0-50 mm surface sample). The bulk material EC or TDS is normally provided in routine laboratory results of potential borrow pit materials.

4.3   Climatic Conditions

Characteristics of the regional climate, seasonal precipitation pattern and seasonal temperature pattern are required.

Obtaining Climate rating ('C' Value)

The project site can be classified regionally, as extremely arid to other in Table 4.1, A value (C_1) is assigned appropriate to the regional climate.

Similarly, using Table 4.1 (b) assign a C_2 score depending on the season of precipitation. In Botswana the rainy season is during summer therefore C_2 value of 3 is appropriate for all cases in Botswana.

Assign the C_3 value for the project location by referring to Table 4.1 (c). The temperature range refers to typical daily range. For example the temperature at Kang, Kgalagadi District, can drop to 10°C or lower at night but rises above 35°C at day time therefore the range is typically between 20°C and 30°C (i.e C_3 value of 2).

The overall rating for the climate ('C') is obtained by multiplying the sum of C_2 and C_3 by C1.

4.4   Combined Risk Evaluation (M x C)

The combined risk value (MC) is obtained by multiplying M by C.

MC Value > 30   =   Very High Salt damage potential
MC Value >20 <30 =   High/Medium potential for salt damage
MC Value <20   =   Low Salt damage potential

Where MC value is greater than 20, special design and construction measures are required in order to prevent damage to bituminous surfacings. High MC values relate directly to high risk of salt damage. Where the MC value is marginal (say 18-22), it is recommended that a detailed enquiry of the history and performance of existing thin surfacings is also desirable, looking in particular for lifting and loss of adhesion between the bituminous surfacing and the underlying layer.

Where MC value is below 20, salt damage precautions are probably not required.
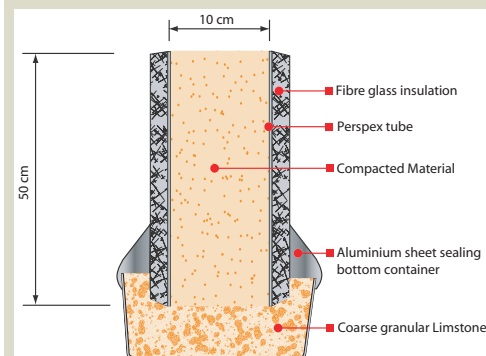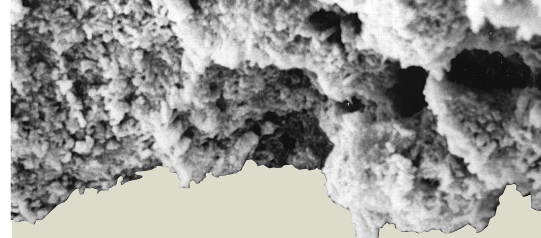
Soil compacted into mould, primed or surfaced and allowed to stand in an oven for a number of days can provide a good indication of whether damage will occur.

>30 Very High
>20 <30 Medium/High
<20 Low

Figure 4.3 Salt damage potential.

Table 4.1 Climate, Risk Evaluation.

Table 4.1 (a) Regional Climate	C_1 Value	Example Locations
Extremely arid	4	
Arid	4	-Tsabong
Semi-arid	6	-Most of Botswana
Island coastal	5	
Others	0	-Kasane

Table 4.1 (b) Precipitation	C_2 value	Example Locations
No marked season of precipitation	2	
Summer precipitation	3	- (Assign 3 for all Botswana cases)
Winter precipitation	1	

Table 4.1 (c) Temperature	Range	C_3 value	Example Locations
Zone T1	>30°C	3	- Extreme South-east - Botswana.
Zone T2	20-30°C	2	- Kang, Ghanzi.
Zone T3	10-20°C	1	- Rarely applicable in Botswana.

Explanatory Notes:
1. *Assign C_1 Value (4.1 (a)) depending on Regional Climate*
2. *Assign C_2 Value (4.1 (b)) depending on Season of Precipitation (this value is 3 for all parts of Botswana).*
3. *Assign C_3 Value (4.1 (c)) depending on typical daily range of temperature.*
4. *Obtain overall Climate risk (C) by adding C_2 and C_3 and multiplying the result by C_1. i.e. $C = (C_2 + C_3) \times C_1$*