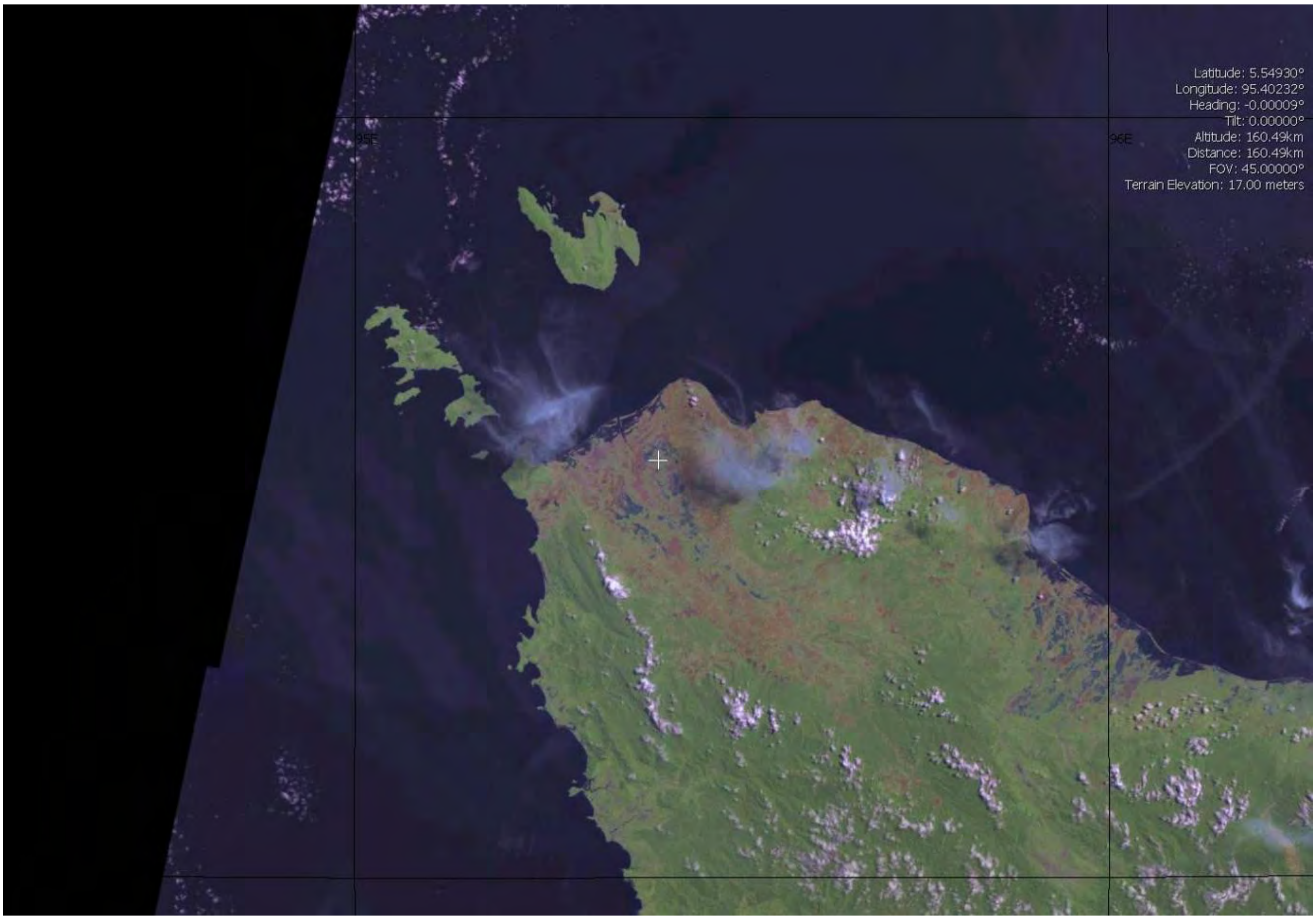
EARTHQUAKE & TSUNAMI EMERGENCY SUPPORT PROJECT

ETESP

Agricultural Component

DESALINISATION & SOIL IMPROVEMENT

MOBILISATION REPORT



UCIL Uniconsult International Limited

Banda Aceh: Version of March 2006

Contents

LIST OF ABBREVIATIONS

AHT	Agrar und Hydrotechnik
Avail	Available
BD	Bulk density
BRGM	Bureau De Recherches Geologiques et Minieres
Ca	Calcium
CEC	Cation exchange capacity
Cl	Chloride
cm	Centimetre
CO_3	Carbonate
COLE	Coefficient of Linear Extensibility
CS	Coarse sand
Cu	Copper
dS	Deci-siemens
EC	Electrical Conductivity
ESP	Exchangeable Sodium Percentage
Exch	Exchangeable
FAO	Food and Agricultural Organization of the United Nations
Fe	Iron
FS	Fine sand
g	Gramme
GIS	Geographical Information System
GPS	Global Positioning System
GWT	Ground water table
ha	Hectare
HC	Hydraulic conductivity
HCO_3	Bicarbonate
HTS	Hunting Technical Services
K	Potassium
km	Kilometre
l	Litre
Lab	Laboratory
LI	Lahmeyer International
LUT	Land Utilisation Type
m	Metre
me	Milli-equivalents
Mg	Magnesium
mg	Milligrammes
mm	Millimetre
MMP	Sir M. MacDonald & Partners
Mn	Manganese
Na	Sodium
P	Phosphorus
PFS	Pre-Feasibility Study
pHp	Soil reaction (pH) measured in paste of saturation extract
pHs	Soil reaction (pH) measured in soil - water suspension
Rep	Replicate
RSC	Residual Sodium Carbonate
SAR	Sodium Adsorption Ratio
SO_4	Sulphate
SSP	Single superphosphate
TDS	Total Dissolved Solids
TOR	Terms of Reference
TSP	Triple superphosphate
USDA	United States Department of Agriculture
Zn	Zinc

Note: the notion 'gravity irrigation' in this report represents 'surface irrigation' as opposed to 'sprinkler' and 'drip' irrigation

1 BACKGROUND, PROBLEMS and TASKS

1.1 BACKGROUND

The Tsunami of 26 December 2004 inundated the Banda Aceh area and dumped vast amounts of sea-water plus debris on the land as well as virtually totally destroying a large proportion of the infrastructure - social and agricultural. The ADB Grant Number 0002-INO: Earthquake and Tsunami Emergency Support Project (ETESP) was set-up to assess the situation and propose remedial measures to assist the area recover from this natural disaster. Uniconsult International Limited (UCIL) was awarded Package 3 – Agriculture Component and UCIL staff mobilised in early September 2005 to commence work.

This is the first report by the Desalinisation and Soil Improvement Specialist prepared after the Inception Report was submitted but Chapter 4 of the Inception has been edited by the specialist and the edited version has been submitted as an addendum to the original report. In this present report it is attempted to document or itemise the factors and tasks to be addressed:

- Extract data from previous soil surveys / land use study reports (e.g. LRDC, ODA, London, 19??) to establish a "baseline"
- Analyse any recent data collected on soils, groundwater, inundation and salinity
- Assess the soil problems caused by Tsunami damage, in particular soil salinisation
- Compile map (GIS inputs?) of the findings / current situation
- Introduce and discuss the subject of soil salinisation and reclamation
- Assess and list the perceived tasks to be undertaken in the process needed for recovery / reclamation
- Detail the data required for reclamation planning and design, identifying possible sources if possible
- Establish the status of water sources for soil reclamation
- Establish the soil and land drainage status (Kovda, 1973 and FAO, 1994)
- Propose soil reclamation and improvement procedures

Many of the above topics have already been discussed in the Inception Report but the soils section of that report has been compiled more on hearsay, comment and gut feeling rather than on solid scientific fact – soil analytical data. There are data sets around and these will have to be made available for the work of the Desalinisation Soil Improvement Specialist to be done to an acceptable standard.

1.2 PERCEIVED SOIL PROBLEMS AND TASKS

Sea-water contains a high concentration of dissolved salts plus, when it comes to shore in the manner of a Tsunami, carries large amounts of suspended or floating material. If the inundation lasts for any length of time salt water percolates into the soils it is flooding and the soil becomes salinised to some extent. If the inundation is for any extended length of time water will start to evaporate and the salt concentration increases, further adding to the salt likely to infiltrate into the soil. Also, any suspended material left on the soil surface may well contain salts or other materials which might well have adverse effects on the soil – this material can be sand, silt or mud-like deposits and all or any can have deleterious effects on soil.

The soils investigations have to establish:

- What was the pre-Tsunami status?

  I. *soil salinity levels*
  II. *soil fertility levels*
  III. *groundwater table level / depth*
  IV. *groundwater table salinity level*
  V. *farmer perception of crop output / production*

This could be one of the most useful tasks and one that must be tackled with some urgency since, having read some of the comments by some of the soil experts, there is a lack of basic soil's knowledge and the consequences arising from normal irrigation – never mind inundation with sea water. It is essential to establish a "baseline" with which to compare the present situation.

- What was / is the duration of the inundation?

  I. *the less the time then the less the salinisation effect*
  II. *What is the areal extent of the area(s) inundated?*
  III. *these need to be mapped and separated from areas where infrastructure has been destroyed but the soil not salinised*
  IV. *what maps are available for the study?*
  V. *what was the pre-Tsunami status of the soils*

Meeting these first two tasks will allow the rest of the necessary work to be done and the programme fulfilled.

- To what degree and to what depth has the soil been salinised?

  I. *has there already been a data gathering exercise?*
  II. *if so who holds the data? If not*
  III. *soil samples need to be taken via some survey work, followed by*
  IV. *soil analysis and a desk study of the data*

Soil salinity and reclamation (Binnies, 1996) is a well documented part of soil science but NOT every soil scientist has the necessary knowledge and background to asses the situation and design necessary remedial measures.

- What type and degree of leaching is required to reclaim the soils and get them back into agricultural use? This requires:

  I. *the soil analytical data suggested above*
  II. *establishment of the "baseline" or pre-Tsunami soil salinity levels*
  III. *establishment of acceptable crops to grow during the reclamation*
  IV. *a source of suitable water for leaching & irrigation*

Some of the comments made in the Inception Report seem to indicate that salinity is not the only problem. Soil nutrient status must be studied before the Tsunami, after the Tsunami and, if the data can be located, the earliest soil surveys carried out – that is the historic data.

- What sources of water are there to use for reclamation leaching?

  I. *if the only source is ground-water and the ground-water (wells) has become salinised is that water of suitable quality for reclamation leaching?*
  II. *Has a surface irrigation water supply been re-established and is there sufficient for the demands of reclamation*

Reclamation is all about leaching and without reliable, suitable water supply the task should not even be started as there will be "apparent" failure – unless nature lends a hand and ensures a good wet season

- How drainable are the soils?

  I. *reclamation requires leaching, that is water is infiltrated into the soil, down through the rooting zone and then removed from the location*
  II. *are there any soil restrictions causing poor drainage?*
  III. *perhaps a soil / land drainage system existed before the Tsunami but that might have been destroyed*
  IV. *If there is not a drainage system then reclamation leaching will remove the salts from the topsoil but increase the salinity of the subsoil and, in time, this can cause further problems or necessitate changes in crops and / or cropping*

Leaching is all about "pushing" the salts (if they still exist) down the soil profile to, in the first instance, below the root or planting zone. As leaching proceeds a greater depth of soil is brought back to acceptable levels and that zone can then be exploited by crop roots for water and nutrients – but the salts are still in the profile and they can migrate back up into the root zone. The leaching must continue to push the salts and the saline leachate well below the root zone and into the water table – that water table then has to be managed and not allowed to rise up to shallow depth, excess must be removed via drainage.

- What is the level of the water-table and just how saline is that water-table?

  I. *at what depth is the existing water-table*
  II. *how saline is the existing water-table*
  III. *is there saline, sea-water intrusion via the water-table?*

There is every chance that in some areas devastated by the Tsunami the soils were already at risk and suffering from salinity before the Tsunami struck and inundated them with salt water. There has been a gradual increase in sea level over the past decade and this is continuing. The result is that more and more salt-water intrusion will happen along coastal strips. There has to be some investigation, perhaps started by the soil scientist and continued by a hydrologist, into water tables close to the coast line.

- Reclamation procedures, with or without amendments, have to be designed / proposed with relevant crop options so that land is brought back into production with as little delay as possible but the designs have to be based on established facts and data for the soils in question

Generally, crop growth can start immediately reclamation is underway and cropping is part and parcel of the reclamation process. The basics to be used / considered for successful reclamation include:

Table 1.1 Basic Facts and Considerations

Item	Facts and considerations
Leaching theory	Reclaim the upper 25 cm and cropping can start. Leaching must continue via normal irrigation, till the salts are removed to depth and hopefully from the site - if the soil dries out the salts will migrate back up the profile
Water	The water should have salts in it as, if too pure and soil is the wrong type, there can be soil damage and slaking could harm the soil permeability If the water is acidic there is the possibility that many, if not most, of the more soluble nutrients have been leached out of the soil
Salinity (ECe)	The salinity of irrigated soils is a function of the salinity (EC) of the irrigation water. If there is addition of large amounts of “pure” rainwater then salinity can be reduced further. But generally salinity of an irrigation soil is governed by the water quality
Soil Water Holding Capacity (AWHC)	Sandy soils have low AWHC and are easy to leach whilst heavy textured soils have high AWHC and can hold more water hence need much more water for leaching and they can be difficult to drain
Water-tables (WT)	In low lying areas and under irrigation schemes there is almost always a water table. If the WT rises too high it will re-salinate the soil. Drainage may be required to ensure saline leachate is removed from the site.

All the above are addressed in the following chapters.

- A system, or systems, for monitoring the status of the soils during and after reclamation work has to be established, including as to who does the monitoring

A monitoring system will add to any baseline database that can be built now and in the future the knowledge and data collected and collated will make any future studies that are required much more straightforward and speedier to complete.

1.3 PREVIOUS STUDIES

As stated in the Inception Report there were very few data sets available to assist the compilation of the initial report. The following people / organizations carried out some soil sampling and analyses but, the actual data sets are not to hand at this time and only summarised results are available.

ACIAR – with ISRI currently collecting / recently collected soil samples from rice and peanut areas in 5 sub-districts of Pidie. Detail on sample numbers, site location, depth and soil type not (yet) established. Use of EM38 salinity probe

ADB – consultant reported on sediments in Aceh Besar that:

- Textures were dominantly sandy
- EC was around 2dS/m – virtually non-saline – whilst original soil was reported as having higher (unspecified) EC
- pH of + / - 6.5
- N,P and K levels were low

FAO – number of samples and sampling depth etc unspecified and a non-standard value for salinity reported 1,000ppm whilst salinity is reported as ECe in dS/m. (1,000ppm roughly equates to an ECe of 1.54 – non-saline class)

IRSI – 3 soil samples from 15 locations in 4 sub-districts – 60 samples. Sampling depths not specified and actual locations not (yet) known

ISRI – collected soil and water samples for determination of pH, N, P, K, OM and soil texture whilst using EM38 for salinity measurement. Detail on sample numbers, site location, depth and soil type not (yet) established

The only data actually available at this time comprises:

- the summaries presented in Tables 4.11 and 4.12 of Chapter 4 of the Inception Report.
- the depth of sediments occurring in Aceh Besar were reported with the following properties:

Depth 2 – 25 cm
Sand content 6 – 53%
Clay content 8 – 43% and

The pH of sediments from Aceh Utara ranged from 6.8 – 8.1

The very limited available data are presented in Section 3.2 of Chapter 3 and it has to be stated now that no mention was found to the results of basic analysis – exchangeable cations etc. The exchangeable cation levels are the basis of fertility and can point the way by indication of deficiencies.

2 SALINE SOILS

2.1 INTRODUCTION

The presence of salts in soil is a widespread phenomenon in many areas of the world but salinity usually results as a consequence of:

- geological weathering under low rainfall conditions,
- by evaporation of waters seeping from higher land
- by upward capillary flow from shallow water tables, sea-water intrusion or from artesian flow
- by accumulation from irrigation waters in schemes with inadequate drainage and water management
- by wind when it picks up spray from rough seas and drops that spray on the land (Hutcheon A., 1967)
- inundation by sea or saline water via natural disasters or human action

There is every possibility that the coastline belt of Northern Sumatera could already have had some soil salinisation, before the Tsunami, as a result of sea-water intrusion via the water-table; this is a naturally occurring phenomenon in low lying coastal areas. The inundation or flooding by sea-water, as happened in the ETESP project area, will have exacerbated any salinisation that already existed.

No matter how the salts got into the soil they can be removed (at a cost) provided the reasons for the salt accumulation are understood and the appropriate remedial measures undertaken. This process of salt removal is termed reclamation.

The general principles for the reclamation of salty soils comprise:

- the removal of salts by leaching
- the replacement of exchangeable sodium by exchangeable calcium and
- the prevention of further accumulation of salt or sodium.

Reclamation is only feasible if water is able to move downwards, carrying the salts below the main root zone. This leaching water is required in large quantities and, in association with the continuing percolation of water from irrigated crops, results in the deeper layers becoming waterlogged and a rise in the water-table towards the surface. In most situations natural drainage is insufficient to cope with the water flow and some sort of artificial drainage becomes necessary at some stage in the reclamation cycle.

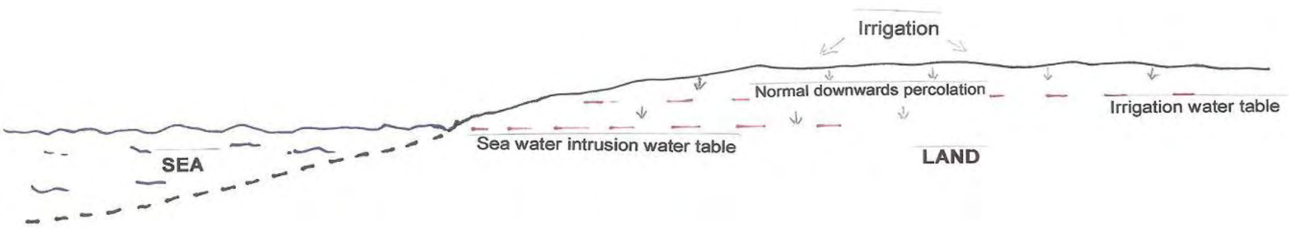
Reclamation (in the first instance) involves the desalinisation of a defined depth of soil (root-zone) to a particular salt content. There will be an initial phase of saline water percolating below the root-zone that eventually merges with the subsurface water table, resulting in increased salinity and movement of the water towards the surface. Subsequent normal irrigation continues to remove salts from the soil and the quantities of salt carried will decrease over time.

Eventually a more or less stable equilibrium is established between soil and irrigation water and then the percolating water salinity is determined by irrigation water quality, the quantity of water applied and the efficiency of irrigation. To a certain extent efficiency of irrigation will be controlled by the method of application of water. The aim is to maintain a net downward flow of water to keep the salts at a prescribed level sufficient to give acceptable crop yields. The quantity of water passing below the root-zone is termed the leaching fraction (LF).

Irrigation water applications must ensure that some water percolates below the root zone to minimise salt accumulation and artificial drainage is often necessary over the long term to remove this percolate. Failure to evacuate this somewhat saline subsoil water usually results in the eventual rise of the water table-with subsequent water-logging and salinisation of the upper productive soil layers. When the soils being reclaimed are close to the shore-line there is always the possibility of the increased water-table being built-up by increased irrigation / leaching merging with the water-table formed by the intrusion of salt-water from the sea because there is little elevation difference. If the water-tables do merge reclamation becomes rather difficult and expensive. This situation must exist in the Banda Aceh area.

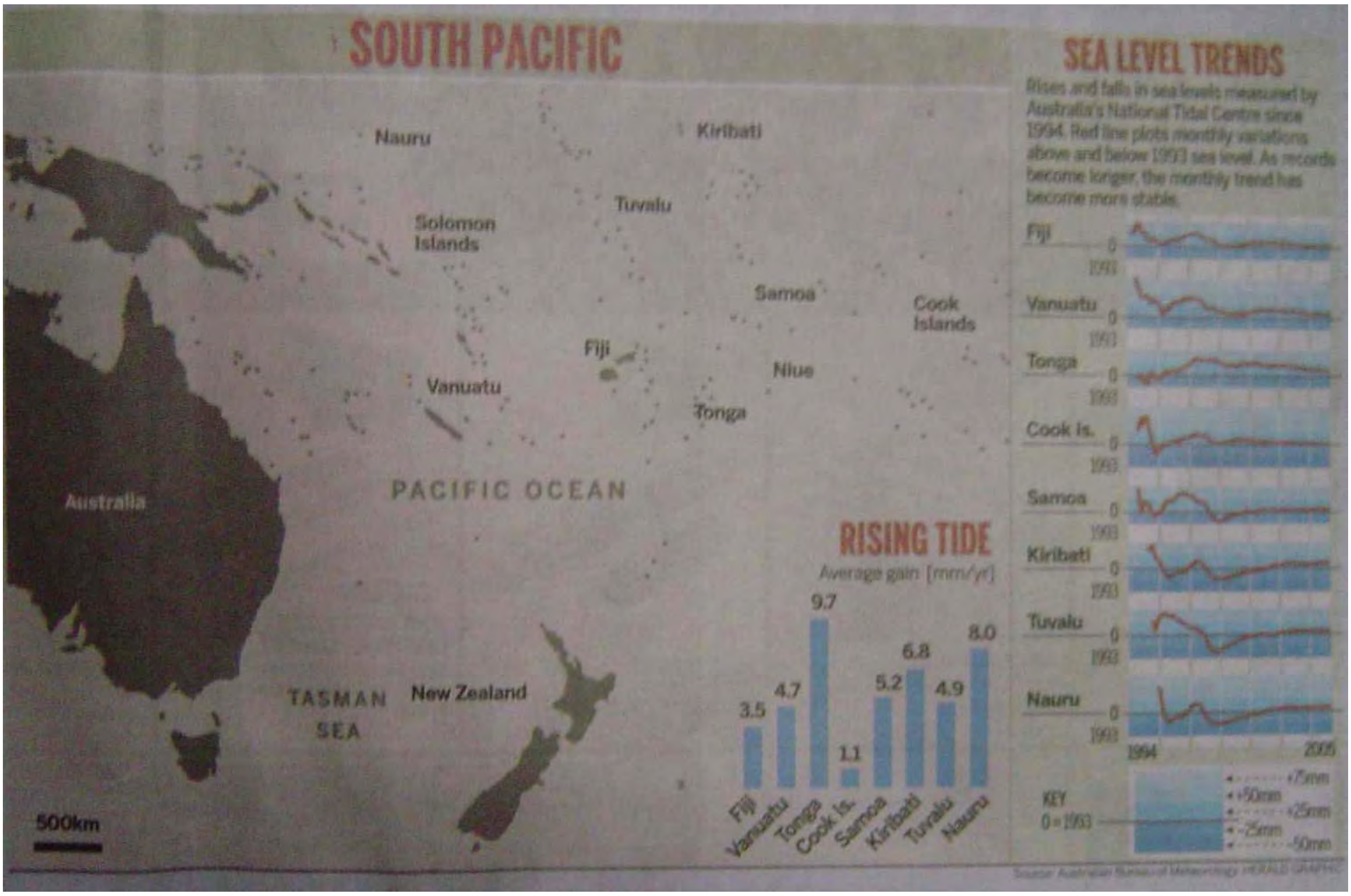
During reclamation and irrigation water, with the salts in solution, will move downwards through the soil profile as long as there is a hydraulic head pushing the water downwards. If irrigation applications cease the hydraulic head is removed and, as the upper soil dries, moisture is drawn back up through the profile since the water will travel upwards due to capillary action - the moisture then evaporates and salts are precipitated out of solution and can be seen as an efflorescence on the surface or on ped faces.

Figure 2.1 Sea-water and Irrigation-water Water-tables



Serious thought should also be given to the current rise in sea-levels being recorded in the South Pacific (South Pacific Geoscience Commission – SOPAC – 2005). Average gains in sea-level of between 1.1 to 9.7 mm / year are being recorded in the Cook Islands and Tonga respectively, with all other islands in the area also experiencing increases. Nauru is probably the closest to the Indonesian Archipelago and Nauru reported increases of 8mm per annum. Before any expensive or expansive interventions are implemented along the shore-line in the Project area the consequences of the interventions being swamped in several years time must be fully analysed and considered.

Figure 2.2 South Pacific islands relative proximity to Sumatera



Salts can only move in solution within the soil and, from the view of crop production, it is the concentration of the more soluble salts that have most effect upon crop yield. Since most plant roots are concentrated near the surface it is the salts in the upper soil that are of the greatest concern.

Salinity control is important once the land is restored to a near salt-free condition; water quality and irrigation management will then ultimately determine the overall soil salt concentration. Irrigation often leads to the longer term accumulation of salt since all waters contains some salt and even irrigation water of low salt content may, in the longer term, result in salinisation of the soil if drainage is restricted.

2.2 TYPE OF SALTS FOUND IN SOIL

The soluble salts that commonly accumulate in soil are those formed by a combination of the cations calcium (Ca), magnesium (Mg), sodium (Na), potassium (K) and the anions bicarbonate (HCO_3), carbonate (CO_3), chloride (Cl) and sulphate (SO_4). These salts may be only very slightly soluble (carbonates of magnesium and calcium), slightly soluble (calcium sulphate) or moderately to extremely soluble (bicarbonates of calcium and magnesium; chlorides of sodium, calcium and magnesium; sulphates of sodium and magnesium; carbonates and bicarbonates of sodium and potassium).

All these compounds are generally found, to a greater or lesser extent, in the soils that have been irrigated and this situation will have been exacerbated by inundation by sea-water in the area under study. The main soluble salts present in the soils need to be established but would most likely be sodium chloride (NaCl) and sodium sulphate (Na_2SO_4), with lesser amounts of magnesium and calcium chlorides. The American saline soil classification does not distinguish between the different types of salt present and relies entirely upon the total salt content, expressed by the EC. This approach has been adopted for use in the present study as it is the internationally accepted format.

2.3 SOIL REACTION

Soil reaction is measured by pH, with low pH values indicating acidity, high values alkalinity and neutral values by pH of +/- 7.0:

- Salts in soil depress the pH to lower values and exchangeable sodium tends to increase the pH
- Measurement of soil pH using a soil-water suspension (pHs) may give values that appear disconcertingly high (pH 9.0 or more) where exchangeable sodium is present due to hydrolysis of sodium. This hydrolysis tends to occur in sandy soils that are poorly buffered. Very occasionally similarly high pH values occur in a few extreme soils containing some sodium carbonate (Janitsky, 1964)
- The pH of the soil saturation paste (pHp) is more representative of the pH of the soil and of most use to indicate the severity of the exchangeable sodium problem.

As indicated in Section 1.3 very little data is yet to hand for reporting or analysis.

2.4 SALINITY AND ALKALI IN SOIL

The American system for classification relies upon the determination of the total salt content (measured by electrical conductivity - EC) and the amount of sodium that occupies the exchange sites of the soil (exchangeable sodium). This is the system adopted for use in this study and will be the principal basis for future discussion on the feasibility for land reclamation.

The understanding of the cause and effect of soil salinity has increased greatly since the pioneering publication ‘The Diagnosis and Improvement of Saline and Alkali Soils’ by the US Salinity Laboratory (1954). The manual published by the American Association of Civil Engineers (ASCE) in 1996 provides a comprehensive review of progress since 1954.

Very little data are available at this time but there has been no indication of alkali conditions.

2.5 IMPORTANT SALINITY AND ALKALI RELATED PARAMETERS FOR IRRIGATION

Soil solution salinity is not an easily defined parameter as it varies with water content. The concept of the saturation extract was introduced to standardise measurements (USDA 1954). This is an extract of a saturated paste (the soil is mixed with water until a paste of a defined consistency is obtained) and two important parameters - the electrical conductivity (**ECe**) and the Sodium Adsorption Ratio (**SAR**) - are determined from this extract. The ratio of the soluble sodium to the soluble calcium and magnesium is used to define the SAR according to the formula:

$SAR = Na / \sqrt{(Ca/2 + Mg/2)}$

The ESP of the soil is often estimated from a nomograph relating SAR to ESP derived from a series of semi-arid soils from the mid-west of America that contained preponderantly hydrous mica (illite) type clay mineralogy. This formula has proved to be a useful tool over a limited range of salt concentrations and a SAR up to 40. However, above this SAR value the estimated ESPs are too high.

The measurement of the ESP by the more traditional approach using displacement of sodium from the soil exchange sites to obtain exchangeable sodium, followed by the measurement of the cation exchange capacity (CEC) also has drawbacks when very salty soils are encountered. There is considerable scope for laboratory error.

The fact that a salty soil has a high ESP, whether calculated by the SAR approach or the exchangeable sodium/CEC method, is, in fact, of only limited interest. The chemistry of mixed salt solutions, of the type usually found in salty soils, generally means that sodium salts will be dominant. Consequently the SAR of the soil solution will be high. Water passing through the soil removes salts and as the EC decreases so does the ESP.

It is not envisaged that there will need to be any studies or analyses into SAR and ESP of Project area soils.

2.6 CLASSIFICATION OF SALT AFFECTED SOILS

2.6.1 The USDA system

Several systems exist for the classification of salty soils of which the American (USDA, 1954) and Russian (Plyusnin, 1961) systems are the most widely used. The American (United States Department of Agriculture, USDA) system is the one most commonly used. The four groups generally defined and used are:

- Non-saline, non-alkali (ECe<4dS/m; ESP<15)
- Saline (ECe>4dS/m; ESP<15)
- Saline-alkali (ECe>4dS/m; ESP>15)
- Non-saline-alkali (ECe<4dS/m: ESP>15)

Soils with an ESP greater than 15 are termed alkali and not alkaline. An alkaline soil is a soil with a pH greater than 7 that may, or may not, have an ESP in excess of 15. Sometimes the term ‘alkali’ is replaced by ‘sodic’ hence saline-sodic soil in place of saline-alkali.

The reality of the situation depends on the cause and severity of the salt problem. Just because a soil is saline (ie. EC >4.0) it is not the end of the world. The threshold salt content has justification, based on effect of seed germination and on potential reduction of crop yield to several agriculturally important crops - especially vegetables and many fruit crops. Having this low threshold salinity, therefore, is a desirable goal that may or may not be achievable. Many crops can be grown in soils having an electrical conductivity greater than 4.0 dS/m and in the final assessment the irrigation water quality may regulate the final level of salinity achievable.

In a similar manner a soil ESP greater than 15 may, or may not, be a problem. The soil may require the addition of an amendment such as gypsum if it falls within the classification of a non-saline-alkali soil and has specific characteristics that render crop growth unacceptable under field conditions.

A saline-alkali soil is a different case. The main concern is the possibility that the soil clay will disperse under irrigation and result in a reduction of the infiltration rate. Many clay soils have low infiltration rates even at low ESP levels. For example, many of the Gezira clays (Sudan) have ESPs in excess of 15 (Robinson et al 1970) yet growth and yield of crops such as cotton, are not affected to any measurable extent despite ESPs of 25 to 35. However, it was shown that some clay dispersion was present. This may be explained by the strong cracking characteristics of these clays (about 80 percent of the clay fraction consists of montmorillonite) that mainly controls water entry. Once the cracks seal, due to expansion of the clay, the infiltration rate reduces to about 1 to 2mm per day.

Table 2.1 Salinity Classes

Description	Salinity class	Range in ECe (dS/m)
Non saline	SC1	0.1 – 3.9
Slightly saline	SC2	4.0 – 7.9
Moderately saline	SC3	8.0 – 15.9
Highly saline	SC4	16.0 – 31.9
Extremely saline	SC5	32.0 – 63.9
Ultra saline	SC6	64.0 – 127.9

NB Some versions of the classification system include “strongly saline” between “moderately” and “highly”

The above classification is the “International” standard and will be used in these studies.

2.7 BORON IN SOILS

High boron concentrations have been measured in highly saline soils but, as ‘highly” saline soils do not appear to have been reported in the study area this element is not expected to be of any importance. If it exists in the soil boron concentrations reduce during leaching albeit at a somewhat slower rate (one-sixth) than the other soluble salts (Reeve et. al., 1955) and eventually equilibrate with the concentration in the irrigation water. If Boron does exist in the soils of the study area it is not expected to be a problem after reclamation. In any case, there is no practical method of removal. (El Seewi et al, 1979)

3 RECLAMATION of SALT AFFECTED SOILS

3.1 PRINCIPLES

The discussion above indicates that the majority of soils are normally capable of reclamation by leaching – and, very often, this is without the need for an amendment such as gypsum. It is mainly a matter of washing the excess salt out of the root-zone until the salt content is reduced to a level where a first (reclamation) crop can be grown. Irrigation in small basins is the traditional method used. High spots within the basin, not covered with water, accumulate salt and precise levelling is important. Furrow irrigation distributes salt in various directions, as do trickle/drip systems. The best way to ensure downward movement of salt is by basin or sprinkler irrigation.

The quantity of water needed to accomplish salt removal depends upon:

- the quantity and types of salts present
- the soil texture
- the depth of soil to be desalinised
- the final desired level of salinity and
- the salinity of the irrigation water.

Salinity usually exerts the most detrimental effect at the seedling stage and salt in the lower layers (provided it does not move upwards) gives less cause for concern.

A soil may be defined as reclaimed (sufficient for many field crops) when the salinity of the upper 50cm is reduced to a concentration that does not significantly affect the yield of the proposed cropping patterns. This has been taken as an average of 4.0dS/m throughout the top 50cm. An ECe range around 4.0 dS/m in the plough layer and 6.0 – 8.0 dS/m in the subsoil should be adequate for the planting of the first crop during the reclamation cycle. Subsequent reclamation irrigation will continue until the desired salinity removal has been achieved. Irrigation losses under a more normal irrigation regime will continue to remove salts from the soil and subsoil.

A formula commonly used and derived by Hoffman (1980) is: C/Co = k/Dlw * Ds-1 and this formula can be rearranged to give the depth of leaching water (Dlw) as:

Dlw = k * Ds * ECo/EC, where

C (EC)	desired soil ECe (dS/m)
Co (Eco)	initial soil ECe (dS/m)
k	constant
Dlw	depth of leaching water (mm)
Ds	depth of soil to be reclaimed (mm)

A "Rule-of-thumb" approach was proposed by Reeve and Fireman (1967) that stated that when Dlw/Ds = 0.5 about 50 percent of the salt is removed over the depth Ds and when Dlw/Ds = 1.0 then 80 percent of the salt is removed over the depth Ds. These observations apply to medium textured soils with a little less water needed for coarser textures (90 percent salt removed) and a little more (70 percent salt removal) for finer textures.

Worked examples using the Hoffman formula are presented later in this document and a spreadsheet has been designed to carry out the calculations once the basic data on:

- existing salinity
- desired salinity and
- soil depth

are determined and entered.

3.2 FACTORS INFLUENCING AMOUNT OF WATER REQUIRED

The quantities of water required for reclamation are calculated based on soil texture, salinity class and ECe of the root zone as presented in Table 3.1

Table 3.1 Factors in Water Requirement for Reclamation

Factor	Limits	
Texture	three textural groups: I. L = Coarse II. M = Medium III. H = Fine	L = sandy loam M = loam, clay loam, sandy clay loam, silt loam H = clay, sandy clay, silty clay, silty clay loam
Salinity class	I. SC3 (mean ECe 12 dS/m) II. SC4 (mean ECe 24 dS/m) III. SC5 (mean ECe 48 dS/m) and IV. SC6 (mean ECe 96 dS/m)	
ECe of root zone	Reduction of the salt content to a mean ECe between 0-50cm of 4.0 dS/m	

3.3 CALCULATION OF AMOUNT OF WATER REQUIRED FOR RECLAMATION

3.3.1 Basic Calculation of Water Requirement

The formula derived by Hoffman (1980) that claimed to incorporate many worldwide studies (eg Nielsen et al, 1966) is considered to be suitable for the present study. The Hoffman formula is: C/Co = k/Dlw * Ds-1 where:

C	desired soil ECe (dS/m)
Co	initial soil ECe (dS/m)
k	constant
Dlw	depth of leaching water (mm)
Ds	depth of soil to be reclaimed (mm)

Rearranging this formula, substituting EC for C and ECo for Co gives:

Dlw = k * Ds * ECo/EC

This formula was derived from leaching tests using the ponded water technique and the constant "k" varied according to the soil texture. However Hoffman (1980) showed that for intermittent irrigation (using an irrigation gift of between 50 and 100mm per irrigation) then "k" becomes 0.1 for all textures. Therefore the quantity of leaching water needed becomes independent of the soil texture. Calculations based on this formula are given in Table 3.2 to reclaim the top 250mm (25cm) and 500mm (50cm) of soil.

Table 3.2 Leaching Water Requirements

Salinity class	Ds (mm)	Constant "k"	ECo dS/m	EC desired	ECo/EC	Dlw (mm)	Dlw m3/ha
SC3	250	0.1	12	4	3	75	750
SC4	250	0.1	24	4	6	150	1500
SC5	250	0.1	48	4	12	300	3000
SC6	250	0.1	96	4	24	600	6000
SC3	500	0.1	12	4	3	150	1500
SC4	500	0.1	24	4	6	300	3000
SC5	500	0.1	48	4	12	600	6000
SC6	500	0.1	96	4	24	1200	12000

NB The above calculations are carried out automatically in a spreadsheet (Leaching water requirements.xls) on addition of the basic data

The quantity Dlw is the amount of water that has to pass through the soil layer of depth “Ds” - it is not the quantity that has to be applied. Soil storage, evapotranspiration and the leaching fraction (LF) of the applied irrigation water that passes into the soil must be considered.

3.3.2 Application Efficiency, Leaching Fraction and Leaching Requirement

Three variables, the field or application efficiency (**AE**), the leaching fraction (**LF**) and the leaching requirement (**LR**), are important in any discussion of salt control. The LF and LR are not the same as the following definitions illustrate:

Table 3.3 Application Efficiency, Leaching Fraction and Leaching Requirement

Application Efficiency	Leaching Fraction	Leaching Requirement
This is the amount of the applied irrigation water that actually enters the root zone.	The LF is the fraction of the applied water that actually passes through the entire root zone and percolates below the root zone, eventually to join the water table.	The LR is the amount of water that must pass through the root zone and into the layer below the root zone to maintain the salt content of the root zone at a desired level.

(a) Field or Application Efficiency

Not all the water that is applied during irrigation enters the soil - some will be used to bring the soil up to field capacity and the rest will percolate into lower layers (leaching water). Application efficiency can be low during the early stages of a reclamation project and for basin irrigation an efficiency of 0.7 (70 percent) can generally be adopted. This means that for every 100mm depth of water applied, 70 mm will enter and be stored in or held by the soil.

Storage in soil depends mainly upon soil texture and the following values can be taken for the available water holding capacity (AWHC) - the amount of water held between wilting point and field capacity. No water will move downwards from a soil layer until FC has been achieved.

Table 3.4 Available Water Holding Capacity (AWC)

Texture group	Texture classes	AWHC, mm/m
L - coarse	sandy loam	120
M - medium	loam, clay loam, sandy clay loam, silt loam	240
H - heavy	clay, sandy clay, silty clay, silty clay loam	200

In other words, if 100mm of water was added to the surface of a sandy loam soil for irrigation or reclamation not the entire top metre of soil would be wetted to field capacity as this soil type needs 120mm to get the top metre wetted. However, if 150mm were to be added then there would be an excess of 30mm which could percolate downwards as leaching water.

(b) The Leaching Fraction (LF)

The Leaching Fraction is defined by the equation:

LF = depth of water leached below root zone /depth of water applied at surface

This quantity of water, the leaching fraction or LF, contributes to the LR. In some cases the unavoidable losses (due to irrigation inefficiency) represented by the LF exceed the estimated LR so further supplies of water for salinity control are unnecessary. Management, soil type and method of irrigation mainly determine the water losses at the field level.

Table 3.5 presents a range of application efficiencies (AE) for various irrigation systems, adapted from Lahmeyer 2004b, with specific values suggested for use in assessing the most likely LR.

Table 3.5 Irrigation Efficiency and the Estimated Leaching Fraction

Irrigation System	Application Efficiency (AE)	Adopted AE %	Estimated LF
Surface Systems			
Basin	60-90	70	0.30
Furrow	50-90	60	0.20
Sprinkler Systems			
Hand Move	70-80	70	0.20
Centre pivot and Linear	70-90	80	0.10
Micro-irrigation Systems			
Surface Drip	90-95	90	0.05
Sub-surface Drip	90-95	90	0.05

(c) The Leaching Requirements (LR)

The Leaching Requirement is a function of the water salinity and soil salinity chosen according to the salt tolerance of the crop and the acceptable level of crop yield reduction.

Leaching requirements (LR) are presented in Table 3.6 for a range of possible crops which might be grown. The LR defines the quantity of water that would have to pass through the root-zone in order to maintain the soil salinity at the level needed to give a 100 percent crop yield.

The formula used to calculate the leaching requirement (LR) was that developed by Rhoades (1974) and is:

$$LR = ECw / (5ECe - ECw)$$

where:

- ECw - electrical conductivity of the irrigation water (dS/m)
- ECe - salinity of the soil saturation extract corresponding to the 100 percent crop yield target (the soil salinity threshold), expressed in dS/m.

The above calculation can be done by entering the data on ECw and ECe into one of the tools developed for project - the spreadsheet: named **LR via ECw &ECe.xls**

Table 3.6 Leaching Requirement for a Selection of Crops

Crop	Wheat	Sorghum	Maize	Lucerne	Ground-nuts	Beans (Vicia)	Potato	Vegetable	Citrus
EC100	6.0	6.8	1.7	2.0	3.2	1.5	1.7	1-2	1.7
LR100	0.01	0.01	0.03	0.03	0.02	0.03	0.03	0.05	0.03
EC90	7.4	7.4	2.5	3.4	3.5	2.6	2.5	1.5-2.5	2.3
LR90	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.03	0.02

EC100 is soil ECe corresponding to 100 percent crop yield

EC90 is soil ECe corresponding to 90 percent of potential crop yield

The LR (LR90 and LR100) for the above crops ranges from 0.01 to 0.05. This means that only one to five percent of the infiltrating irrigation water has to pass below the root-zone to maintain soil salinity at a level that will have no effect upon crop yield. This is a direct result of the excellent quality of the water being used.

The estimate of the amount of water that is unavoidably lost below the root-zone (LF) during irrigation (Table 3.5) varies from 0.05 to 0.40 (five to forty percent of infiltrated water). Since the LF exceeds the LR by a considerable amount salt accumulation in the soil due to irrigation will not be a concern.

Reclamation by leaching and removal of salt depends upon the maintenance of soil permeability. This is affected by the provision of a sufficiently high electrolyte concentration in the soil solution to offset the dispersing effect of exchangeable sodium (Quirk et al, 1955).

3.4 PROCEDURES FOR RECLAMATION

Reclamation leaching can be attempted by continuous flooding or by intermittent flooding and the reclamation can be done without any attempt to grow a crop but is normal nowadays to attempt to grow a crop with known tolerance to some salinity from virtually the first reclamation flooding or irrigation.

It has been found that intermittent flooding (irrigation) is more efficient at removing salt than continuous flooding. The theory behind this is that after a flooding, or irrigation, the soil dries out to some extent and salts trapped within the pores and capillaries of the soil are drawn to the surface of the soil unit (ped) as the water evaporates. At the next and subsequent flooding, or irrigation, this salt is on the ped surface and easily dissolved and removed via the downward movement of the leaching water.

Reclamation can consist of leaching alone or with the application of amendments, such as gypsum. The soils under investigation should, in theory, require leaching alone but Table 3.7 is presented to allow determination of the correct procedure.

Table 3.7 Criteria to Determine Procedure for Reclamation of Salt Affected Soils

Reclamation required	Determined existing soil parameters
Leaching only plus good management	Exchangeable Na <1.0mmolc/l provided pHp 9.0 or less
	Chloride/sulphate ratio <5.0 in saturation extract
	Chloride/sulphate ratio >5.0 provided Cl>Na i.e. presence of calcium and magnesium chlorides
	pHp 8.9 or less, no sodium carbonate.
Leaching with amendments plus good management	pHp range 9.0-11.0
	Sodium carbonate present in saturation extract
	Soluble Calcium and Magnesium <4.mmolc/l
	Chloride/sulphate >5, no gypsum in soil.

Laboratory data from the soils under investigation have to be examined against the above key criteria to help decide the appropriate reclamation method.

3.5 OTHER FACTORS TO BE CONSIDERED

Most of the following items discussed may well not have much relevance in the Project Area but they are included for the sake of completeness and just in case they turn out to be relevant.

3.5.1 Topsoil slaking and dispersion

Slaking refers to the breakdown of aggregates into sub-aggregates. Dispersion refers to the release of individual clay platelets from aggregates. Both phenomena can occur at ESPs less than 15 if the electrolyte concentration in the soil solution is low.

During irrigation the EC of the soil solution of the topsoil is essentially that of the infiltrating water and the ESP / SAR that of the soil (i.e. since ESP is buffered from rapid change by the soil CEC). Representative threshold values for SAR and ECe of irrigation water to maintain permeability are provided by Rhoades (1982) and incorporated into the FAO Guidelines for Water Quality (FAO, 1994). The threshold values of topsoil SAR and EC irrigation water to maintain permeability as plotted by Rhoades is essentially linear:

Table 3.8 Relationship between SAR and EC water

EC water (dS/m)	0.5	1.0	2.0	3.0
SAR (topsoil)	5	10	20	30

SAR values greater than those quoted, compared to the EC of the irrigation water, may result in a decrease in permeability. There can be significant differences in the susceptibility of soil to disperse and the above are only guidelines, not certainties.

Water quality cannot be changed and hence soil and water management will be needed. It will be important to maintain, if not improve, soil stability by increasing the organic matter content - by application of manure and/or incorporation of a green manure crop. The use of single superphosphate fertiliser can possibly be advocated as part of the reclamation process as this fertiliser contains a significant amount of gypsum. In addition the phosphate would help encourage root development.

3.5.2 Procedures during the reclamation period

Leaching and cropping should proceed together, to the extent possible, as cropping aids reclamation.

(a) Land preparation

All the project lands will have to be checked to determine if levelling is required before reclamation can start. Careful and efficient levelling is essential for gravity irrigation, less so if sprinkler irrigation is contemplated. For gravity irrigation, levelling should be carried out so that the difference in height between any two parts of the field is not more than 50mm (with irrigation depth 100mm). The soil should be ploughed to a depth of 250mm, followed by a further two or three ploughings until a reasonable tilth is obtained.

For sprinkler irrigation land levelling is not as critical as with gravity irrigation. Nonetheless, the land needs to be smoothed, sub-soiled and ploughed to attain a suitable tilth.

(b) Deep sub-soiling

Previously irrigated soils often have hard (when dry) and compacted sub-soil layers that will resist water penetration. This compaction can have been brought about by long term puddling with the regular ploughing and trampling by buffalo (if used) – basically this layer is a plough pan. If such layers are suspected then bulk density of the layers in question should be measured. Reclamation will not succeed if water cannot readily penetrate into the subsoil. It is essential that any physical constraint to water penetration are removed by an initial ripping of the soil down to a depth of 50cm at a one-metre interval when a hard or plough pan is identified. Two passes to be made, the second at right angles to the first.

(c) Irrigation and Permeability

Gravity irrigation should be frequent, preferably using small basins of approximately 14 x 20m. A rotational frequency of once per week is desirable, if the irrigation supply will allow, with a water depth of 100mm per application. Weekly irrigation of 100mm will enable the surface water to disappear within 24 hours, assuming a minimum infiltration rate of 4.0mm/hr – however, some Indonesian paddy fields are known to have much lower infiltration rates so the process could take longer than envisioned. The permeability of the subsoil will determine the rate of leaching attainable and the reason why an initial ripping measure recommended before reclamation begins. A surface and subsoil permeability rate of at least 4mm/hour needs to be available for the weekly irrigation schedule otherwise crop yield may be reduced by lack of root aeration.

With sprinkler irrigation, the application rate will determine the rate of salt removal. The need is to apply the equivalent of that for basin irrigation ie. 1,200mm with efficiency of 0.8 (winds will increase evaporation of water so 960mm go into the soil. This means applying 14mm per day, of which 12mm/day should infiltrate.

(d) Soil conditions

At this time little or no information on soil conditions – fertility, fertility potential etc – has been studied, as and when data are located this will be done. However, there have been a few indications that fertility may be poor and improving fertility status should be included from the commencement of reclamation. The addition of animal manure or compost, or indeed any other organic matter source such as a green manure crop can be an essential part of the reclamation process. Phosphate, as well as nitrogen, needs to be incorporated to ensure root extension to lower layers. Manure, whilst an excellent conditioner, does not supply much phosphate.

3.5.3 Progress of reclamation

The expected progress achieved during reclamation leaching can be calculated based on the soil type and the depth of water being applied as an irrigation "gift"

An example of this procedure is presented in Chapter 4, refer Figure 4.2.

3.5.4 Cropping during reclamation

A simple cropping sequence is recommended, based on the type of crops familiar to the smallholder farmer and those that will make a contribution, however small, to his income and food security.

Successive leaching combined with cropping, even if initial crop yields are low, is the best approach since crop growth stimulates infiltration and contributes to the needed increase in soil organic material. Also, in all soils, apart from the most saline, some crop will be obtained, even if the yield is low. An income, albeit small and possibly uneconomic, is always welcome to a smallholder farmer.

Traditionally saline leaching studies have been modelled on wheat as the first crop. However, barley is more salt tolerant and a better alternative, though it has not been established if cultivation of this crop in the area is done. With the relative tolerance of rice in consideration with the relatively low levels of salinity suspected it is suggested that rice is used for about 50% of the initial cropping reclamation.

3.5.5 Crop salt tolerance

The soil salinity tolerance data quoted in literature apply mainly to crop growth from the late seedling to the maturity stage. Crop tolerance during germination and early seedling stages may be different and poor germination often restricts the final crop yield. Information on germination under saline conditions is only available for a few crops. Maas (1984) measured the relative tolerance of various crops, including some vegetables, at the germination stage. Some of his results are tabulated by FAO (1985) on page 40. This table clearly shows that seed germination of several vegetables (tomato, onion and bean) is reduced by about 50 percent in the soil salinity range (ECe) between 6.0 and 8.0 dS/m. FAO (1985) therefore recommend that the surface soil salinity should not exceed 4.0 dS/m at planting. This requirement has been considered for cropping during the reclamation period.

3.5.6 Post reclamation soil salinity

Reclamation (in the first instance) involves the desalinisation of a defined depth of soil (root-zone) to a particular salt content. There will be an initial phase of saline water percolating below the root-zone that eventually merges with the subsurface water table, resulting in increased salinity and movement of the water towards the surface. Subsequent irrigation continues to remove salts from the soil and the quantities of salt carried will decrease over time. Eventually a more or less stable equilibrium is established between soil and irrigation water and then the percolating water salinity is determined by irrigation water quality, the quantity of water applied and the efficiency of irrigation. The aim is to maintain a hydraulic head to ensure a net downward flow of water to keep the salts at a prescribed level sufficient to give acceptable crop yields. The quantity of water passing below the root-zone is termed the leaching fraction.

The salinity of the soils will continue to decrease following reclamation until the soil salinity reaches a value that is more or less in equilibrium with the salinity of the irrigation water.

4 STUDY of DATA on SOILS, CLIMATE & CROPPING

4.1 INTRODUCTION

As stated in the earlier chapters very little soil data were available to the consultant on arrival in early October. However, some attempt is made in this chapter to detail some of the known and potential soil problems of the area, with or without tsunami damage. The potential problems are listed below and further elucidation is offered in Table 4.1. Known and potential soil problems:

- Physical damage – arising from the tsunami
- Chemical damage – arising from the tsunami
- Long-term, inherent fertility problems
- Salinisation arising from sea-water intrusion – long term on-going problem

Table 4.1 Damage and Potential Soil Damage

Damage Type	Detail	Type	Effects
Physical	Tsunami deposits *	Mineral material – sands	Dilution effects: • AWHC reduction • Fertility potential reduction
		Mineral material – silt / clay	Sealing surface and chemical effects: • Finer material, especially silts, can seal the surface and reduce infiltration • If silts dry in-situ they can crust and prevent seedling emergence
		Organic materials	Can increase fertility Can acidify if sulphate present
		Infrastructure	Irrigation & drainage systems damage
Chemical	Sea water & deposits	Salinisation from sea-water inundation	Depends on soil type and length of flooding • Sandy soils badly salinised but easily reclaimed • Sawah soils (clays) less salinised but less easy to reclaim
		Acidification	If there are sulphates present along with OM deposits and the soils dry-out there is danger of possible acid-sulphate soils
Other	Sea water intrusion	Water-table salinity	If saline, sea-water water table rises then soil will be salinised
	Long term infertility	Inherent acidification	Dryland soils under high rainfall can have most or all soluble minerals & nutrients leached out & soil acidifies, plus aluminum can build up and become toxic for some crops

*Note * the word <u>silt</u> is not used when referring to materials deposited by the tsunami since silt is a specific constituent of all soils – what we have are deposits*

As detailed in Section 1.3 studies have already been carried out in several Tsunami effected areas by taking soil samples for laboratory analyses and, often, salinity has been determined in the field using a salinity probe – which greatly speeds up the task and gives virtually instant readings for salinity.

However, at this time the datasets have not been located and all that is available for some "first" estimates are summaries. All available data should be studied; this includes any older (historical) data as that may assist in eliminating some possible problems if not solving them.

These data sets will be tracked down and, hopefully, released to the Desalinisation Specialist to allow a truly scientific base to be used for tackling the problem. There are quite sophisticated tools and computer routines to assist in the requirements for reclamation – it is not "ROCKET SCIENCE" but it is based on solid, proven soil science, has been / is used on projects with serious salinity problems, does work and will be used in this study.

4.2 DATA AND DATA INTERPRETATION

The data-sets which were available in October have been manipulated and analysed to see if any useful information or leads might be found. The data that has been used largely comes from MapFrame and has normally been used in the Interim Report.. It has to be stated here that there have obviously been different versions of MapFrame and it appears that minor adjustments have been made to some of the data sets – usually areas of Kecamatan and Desa.

4.2.1 Climatic Data

Precipitation varies widely in the various regions and it is not quite as simple as the east coast having low and west coast high precipitation respectively. The data were analysed and manipulated and the resultant table shows the results, which are then shown graphically.

Table 4.2 Long Term Precipitation by District (Kecamatan)

District No	Name	Location	Annual long term Pptn (mm)	Pptn in 1999	1999 as % of average
1	Simeulue	SW	1127	1244	110
		Average	**1127**	**1244**	**110**
11	Aceh Utara	E	1365	1318	97
10	Bireuen	E	1613	1541	96
8	Aceh Besar	N	1668	1057	63
		Average	**1549**	**1305**	**85**
9	Pidie	N	1889	1807	96
5	Aceh Timur	E	2222	3044	137
16	Aceh Jaya	W	2649	2578	97
		Average	**2253**	**2476**	**110**
7	Aceh Barat	W	3149	2809	89
12	Aceh Barat Daya	W	3303	2774	84
15	Nagan Raya	W	3360	2990	89
		Average	**3271**	**2858**	**87**

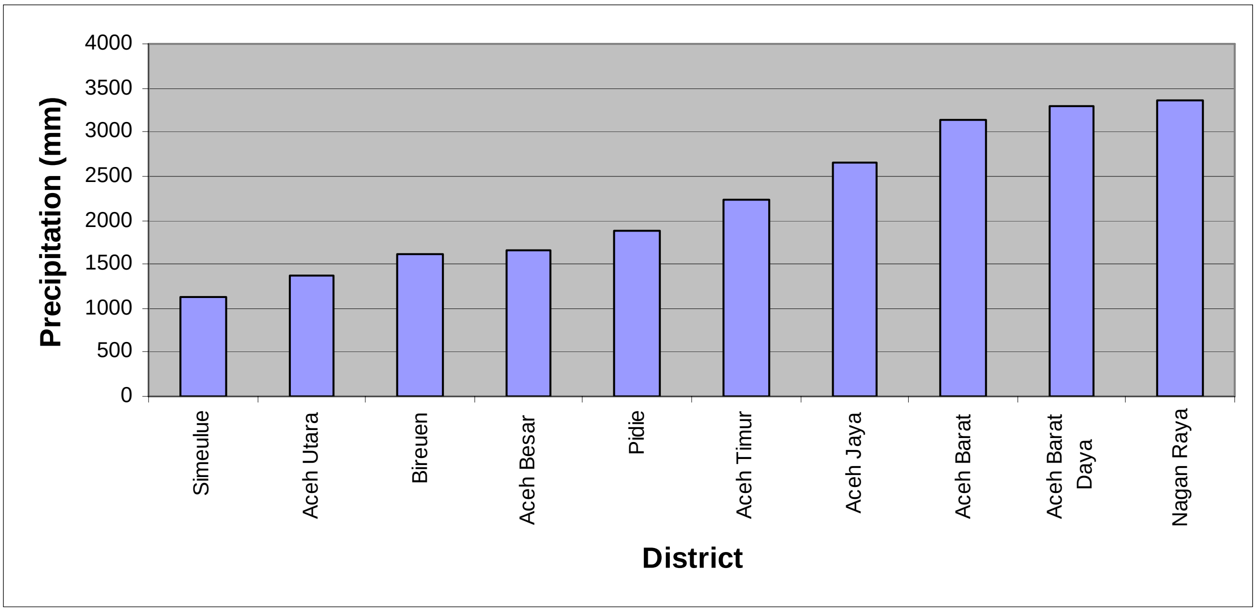
It can be seen in Table 4.2 that groupings based on geographical location do show variations with:

- The island of Simeulue having by far the lowest precipitation of just over 1100mm / annum
- An average of around 1500mm found along the N and / or E coasts
- An average of about 2250mm scattered in west to east but at about the same latitude
- The lower west coast having the highest – overall average in excess of 3250mm/annum

Note: Where a Kecamatan is more on a north facing coast it has been labelled as such rather than west

Figure 4.1 Districts (Kecamatan) in the Study and Long Term Precipitation

Figure 4.2 Long Term Precipitation by District (Kecamatan)



This does mean that natural leaching and reclamation will be vastly different in the different areas and that the amount of leaching water applied must take some, certainly not all, of the predicted rainfall into account.

One unexpected anomaly is that of the third group (Districts 5, 9 and 16) which appear to be governed by latitude (how far north) and not location on the east or west coast; in fact what has been referred to as the east coast is, in fact, a north facing coast.

It is less easy to try and explain the other anomaly, that of precipitation on Simeulue being about one third that of the areas which are slightly further north and on Sumatera Island. It could be that Simeulue is in a massive rain shadow – whatever the reason, any reclamation here will have to rely much more heavily on irrigation water supplies and the rainfall almost ignored.

4.2.2 Crop Data

The data for three Kecamatan were analysed and the following table compiled. The three Kecamatan were selected at random with the intention of trying to establish just what proportion of soils classified (ADB Mapframe) as wetland and dryland were cropped as sawah and ladang before the tsunami.

Table 4.3 Wetland and Dryland % cropped as Sawah and Palawija pre-tsunami

					Pre-tsunami (Ha)				
Kec No	**Name (Kecamatan)**	**Coast**	**Annual long term Pptn (mm)**	**Gross Kec Area (Ha)**	**Area Sawah cropped**	**Area Palawija cropped**	**Total Area Cropped**	**% of Sawah land cropped**	**% of Palawija land cropped**
5	Aceh Timur	E	2222	607,143	35,746	3,151	38,897	79.1	1.1
8	Aceh Besar	N	1668	276,276	30,421	12,148	42,569	81.5	5.5
16	Aceh Jaya	W	2649	275,009	9,294	3,918	13,212	20.1	1.8

As can be seen about 80% of wetland in Aceh Timur and Besar were cropped as Sawah, whilst only 20% appeared to have been cropped in Aceh Jaya. However, it is the percentages of dryland areas cropped as Palawija that should raise questions – why, if the percentages are correct, was such a low percentage of land cropped as Sawah? The highest percentage was over 5 whilst the others were between 1 and 2% of the land classified or labelled as suitable for dryland cropping. Could this suggest that farmers did not try to grow ladang crops for a reason, such as fertility or other problems giving poor yield, or was it simply due to difficulties in accessing the farms due to the "unrest"? If the data are correct and the analysis done above valid the reasons have to be investigated and answers sought to improve the situation.

4.2.3 Soils Analytical Data

The data from Table 4.11 of the Inception Report has been extracted and is presented below in Table 4.4 and some of the data used in Section 4.5.

Table 4.4 EC of Soils from Aceh Utara, Bireuen and Pidie

	Electrical Conductivity (dS/m)					
District	**January**	**Salinity Class**	**Reclamation needed?**	**March**	**Salinity Class**	**Reclamation needed?**
Aceh Utara	44 – 100+	SC5 – SC6	Yes	7 – 17	SC2 – SC4	Yes
Bireuen	1.0 – 6.5	SC1 – SC2	No	0.1 – 3.2	SC1	No
Pidie	5.0 - 10.0	SC2 – SC3	Yes	0.2 – 2	SC1	No

As can be seen above the "salinity" class has been appended to the data and a decision made as to whether reclamation is required or not. The principal is that soils are considered "reclaimed" when ECe falls to 4 dS/m or less hence when the class is SC1 no reclamation is needed.

4.3 USE OF DATA AND RECLAMATION TOOLS

The next step is to use one of the "tools" which has been developed as an Excel spreadsheet.

Figure 4.3 Tool for Determining Leaching Water Requirement

LEACHING WATER REQUIREMENT DETERMINATION

Based on formula of Hoffman (1980) $Dlw = k*Ds*ECo/EC$

Where:

Dlw	Depth of leaching water (mm)
Ds	Depth of soil layer (mm)
ECo	Electrical conductivity of soil needing reclaimed (dS/m)
EC	Desired electrical conductivity once soil is reclaimed (dS/m)
k	Constant

Refer: Salinity & Reclamation *A.A.Hutcheon October 2005*

Irrigation Leaching Progress *A.A.Hutcheon October 2005*

To determine how much irrigation water has to be applied to achieve a salinity of 4 dS/m for the soils requiring reclamation (at the time the samples were taken) the values of / for the various factors were entered into Table 4.6:

- original salinity has been entered into in column 2 (ECo)
- depth of soil to be reclaimed is entered into column 4 – in this case 250mm, the root zone
- the salinity that one wants to achieve is entered into column 6 (Desired EC – taken as 4 dS/m)

The results would be quite different if it was decided to reclaim to very low levels – say 2dS/m – and if it was decided that the whole profile depth should be reclaimed, say to 1000mm (1 metre). For the soils in question it would apparently be possible to leach to these very low levels of salinity since the data in Table 4.1 indicate that it is possible.

In both Bireuen and Pidie the leaching effect of the precipitation has done the job and the salinity for the depth reported has fallen well below the SC1 threshold. However, one has to ask:

- Are these reported figures accurate – there is no reason for them not to be!
- If the salinity levels are falling to such low levels there is just the possibility that everything, including nutrients, has been leached out of the soil
- What level of salinity would be achievable using irrigation water rather than rain-water on the assumption that, like most irrigation waters, there is some salt content in the irrigation water.

Table 4.5 Determination of Depth of Leaching Water to Reclaim Root Zone

Enter data Site / Sample Number	*Initial* ECo dS/m	*Initial EC* Salinity class	Depth of Soil Ds (mm)	Constant "k"	*Desired EC* EC dS/m	*Desired* Salinity class	ECo/EC	Leaching Water Required Dlw (mm)	Leaching Water Required Dlw m3/ha
January									
Aceh Utara - max	100	SC6	250	0.1	4	SC2	25.0	625	6250
Aceh Utara - min	44	SC5	250	0.1	4	SC2	11.0	275	2750
Bereuen – max	6.5	SC2	250	0.1	4	SC2	1.6	41	406
Pidie – max	10	SC3	250	0.1	4	SC2	2.5	63	625
Pidie – min	5	SC2	250	0.1	4	SC2	1.3	31	313
March									
Aceh Utara - max	17	SC4	250	0.1	4	SC2	4.3	106	1063
Aceh Utara - min	7	SC2	250	0.1	4	SC2	1.8	44	438

Whatever level of salinity was to be achieved using irrigation water alone it would be further reduced via the leaching that ensues from rainfall. As can be seen between 31 and 625mm of water (between 313 – 6250 cubic metres per hectare) would have to percolate through the root zone to achieve the 4dS/m level.

The above figures would be used by the irrigation engineers / department to allow them to determine if sufficient irrigation water could be supplied to meet the target.

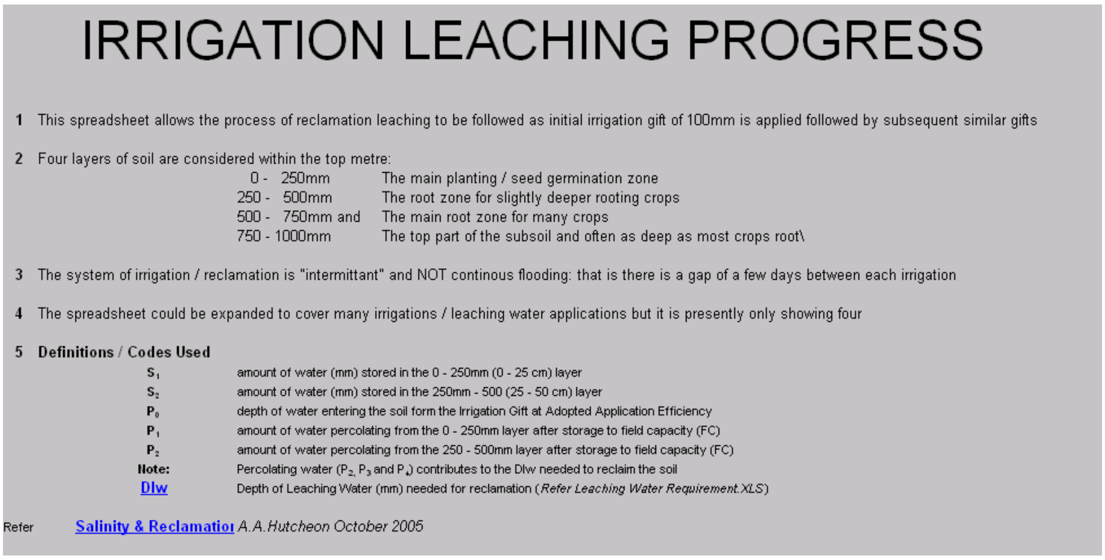
The above calculations are based on reclaiming the top 250mm of the soil profile as this is the main aim or target in the reclamation process in that it would allow a crop to be planted very quickly once the process is started. However, the reclamation process would not be limited to just the top 250mm if irrigation gifts totalling application of, for example, 275 to 625mm were applied.

The reclamation process recommended for adoption is the “intermittent” system and irrigation gifts are usually around 100mm – this can be adjusted upwards as required to give speedier reclamation and the figure of 100mm is often quite close to what the farmer applies during normal irrigation when cropping.

In the “intermittent” system the gifts are usually applied at weekly intervals which allow the water that is applied to enter as far into the soil as it can and also give time for the surface to dry out a bit before the next irrigation. If we follow the example for the highest salinity recorded in January 2005 where 625 mm of water needs to pass down through the soil it is obvious that 6 irrigations of about 100mm or 4 of 150mm have to be applied.

The next “tool” can then be used with the data and this time the results will show just how far down the profile the 4 irrigations option will have leached.

Figure 4.4 Tool for Determining leaching Progress


IRRIGATION LEACHING PROGRESS

1 This spreadsheet allows the process of reclamation leaching to be followed as initial irrigation gift of 100mm is applied followed by subsequent similar gifts

2 Four layers of soil are considered within the top metre:

0 - 250mm	The main planting / seed germination zone
250 - 500mm	The root zone for slightly deeper rooting crops
500 - 750mm and	The main root zone for many crops
750 - 1000mm	The top part of the subsoil and often as deep as most crops root\

3 The system of irrigation / reclamation is "intermittant" and NOT continous flooding: that is there is a gap of a few days between each irrigation

4 The spreadsheet could be expanded to cover many irrigations / leaching water applications but it is presently only showing four

5 **Definitions / Codes Used**

S_1	amount of water (mm) stored in the 0 - 250mm (0 - 25 cm) layer
S_2	amount of water (mm) stored in the 250mm - 500 (25 - 50 cm) layer
P_0	depth of water entering the soil form the Irrigation Gift at Adopted Application Efficiency
P_1	amount of water percolating from the 0 - 250mm layer after storage to field capacity (FC)
P_2	amount of water percolating from the 250 - 500mm layer after storage to field capacity (FC)
Note:	Percolating water (P_2, P_3 and P_4) contributes to the Dlw needed to reclaim the soil
Dlw	Depth of Leaching Water (mm) needed for reclamation (*Refer Leaching Water Requirement.XLS*)

Refer Salinity & Reclamatio *A.A.Hutcheon October 2005*

In this spreadsheet minimal information requires to be entered and decisions have to be made, the section of the spreadsheet where this is done is shown as Figure 4.3.

Figure 4.5 Data Entry

Texture Group	Adopted AWHC (mm / m)	Adopted Application Efficiency (AE)	Irrigation Gift (mm)	Depth of water entering soil (mm)	The values in the boxes on the left can be changed for:	
L	120	0.7	150	105	AWHC	- change if actual and not estimated figures exist
M	240	0.7	150	105	AE	- change if a better or poorer efficiency is established
H	200	0.7	150	105	Irrigation Gift	- change if larger or smaller amounts of water are applied at each irrigation

This tool allows three different soils to be assessed at one time and, as data are not likely to easily located, the main information required is that:

- the texture (texture class) of the soil has to be known
- the size of the irrigation gift has to be known

None of this requires laboratory analysis and texture can be determined by any competent soil surveyor. There are three categories to use:

L	Light	sandy soils
M	Medium texture	loamy soils
H	Heavy textures	clayey soils

The available water or moisture holding capacity (AWHC) of each category has been entered into the formula in the spreadsheet. The irrigation gift has been discussed previously and the default is normally 100mm but for the example being presented the gift is set at 150mm.

Table 4.6 Leaching Progress down the Profile

Texture Group	Adopted AWHC (mm / m)	Adopted Application Efficiency (AE)	Irrigation Gift (mm)	Depth of water entering soil (mm)
L	120	0.7	150	105
M	240	0.7	150	105
H	200	0.7	150	105

The values in the boxes on the left can be changed for:

AWHC - change if actual and not estimated figures exist

AE - change if a better or poorer efficiency is established

Irrigation Gift - change if larger or smaller amounts of water are applied at each irrigation

FIRST IRRIGATION

		Top Layer 0 - 250 mm			Second layer 250 - 500mm				Third layer 500 - 750mm				Fourth layer 750 - 1000mm			
Texture Group	Depth of water infiltrating (mm)	Layer can hold (mm)	Depth (mm) water stored	Balance in layer for percolation	Layer can hold (mm)	Layer receives (mm)	Depth (mm) water stored	Balance in layer for percolation	Layer can hold (mm)	Layer receives (mm)	Depth (mm) water stored	Balance in layer for percolation	Layer can hold (mm)	Layer receives (mm)	Depth (mm) water stored	Balance in layer for percolation
Formula	P_1	*Calc from AWHC*	S_1	$P_1=(P_1-S_1)$	*Calc from AWHC*	P_1	S_1	P2	*Calc from AWHC*	P2	S3	P3	*Calc from AWHC*	P3	S4	P4
L	105	30	30	75	30	75	30	45	30	45	30	15	30	15	15	0
M	105	60	60	45	60	45	45	0	60	0	0	0	60	0	0	0
H	105	50	50	55	50	55	50	5	50	5	5	0	50	0	0	0

Notes:

For the sandy soil this first irrigation will leach salts from the top 25 cm down into the 25 - 50cm layer and start leaching into the third layer

For the medium and heavy soils there is little leaching as the soil in layer 1 has just reached field capacity hence there is little to percolate to layer 2

This first irrigation is a pre-planting irrigation to start flushing salts out of the planting zone

SECOND IRRIGATION

		Top Layer 0 - 250 mm			Second layer 250 - 500mm				Third layer 500 - 750mm				Fourth layer 750 - 1000mm			
Texture Group	Depth of water infiltrating (mm)	Layer Already holds (mm)	To reach FC need (mm)	Balance in layer for percolation	Layer Already holds (mm)	Layer receives (mm)	Depth (mm) water stored	Balance in layer for percolation	Layer Already holds (mm)	Layer receives (mm)	Depth (mm) water stored	Balance in layer for percolation	Layer Already holds (mm)	Layer receives (mm)	Depth (mm) water stored	Balance in layer for percolation
Formula	P_0	*50% of irrig 1*	S1	$P_1=P_0-S_1$	*From Irrig 1*	P_1	S_1	P2	*From Irrig 1*	P2	S3	P3	*From Irrig 1*	P3	S4	P4
L	105	15	15	90	30	90	30	90	45	90	30	105	15	105	30	90
M	105	30	30	75	45	75	60	60	0	60	60	0	0	0	0	0
H	105	25	25	80	50	80	50	80	5	80	50	35	0	35	35	0

Notes:

Assumes the top layer retains 50% of water absorbed during irrigation No 1 with 50% being lost via evaporation etc

Assumes second layer has not lost any of the water gained from first irrigation

THIRD IRRIGATION

		Top Layer 0 - 250 mm			Second layer 250 - 500mm				Third layer 500 - 750mm				Fourth layer 750 - 1000mm			
Texture Group	Depth of water infiltrating (mm)	Layer Already holds (mm)	To reach FC need (mm)	Balance in layer for percolation	Layer Already holds (mm)	Layer receives (mm)	Depth (mm) water stored	Balance in layer for percolation	Layer Already holds (mm)	Layer receives (mm)	Depth (mm) water stored	Balance in layer for percolation	Layer Already holds (mm)	Layer receives (mm)	Depth (mm) water stored	Balance in layer for percolation
Formula	P_0	*50% of irrig 2*	S1	$P_1=P_0-S_1$	*From Irrig 2*	P_1	S_1	P2	*From Irrig 2*	P2	S3	P3	*From Irrig 2*	P3	S4	P4
L	105	15	15	90	30	90	30	90	30	90	30	90	30	90	30	90
M	105	30	30	75	60	75	60	75	60	75	60	75	0	75	60	15
H	105	25	25	80	50	80	50	80	50	80	50	80	35	80	50	65

Notes:

Assumes the top layer retains 50% of water absorbed during irrigation No 2 with 50% being lost via evaporation etc

Assumes second and subsequent layers has not lost any of the water gained from first irrigation

FOURTH IRRIGATION

		Top Layer 0 - 250 mm			Second layer 250 - 500mm				Third layer 500 - 750mm				Fourth layer 750 - 1000mm			
Texture Group	Depth of water infiltrating (mm)	Layer Already holds (mm)	To reach FC need (mm)	Balance in layer for percolation	Layer Already holds (mm)	Layer receives (mm)	Depth (mm) water stored	Balance in layer for percolation	Layer Already holds (mm)	Layer receives (mm)	Depth (mm) water stored	Balance in layer for percolation	Layer Already holds (mm)	Layer receives (mm)	Depth (mm) water stored	Balance in layer for percolation
Formula	P_0	*50% of irrig 2*	S1	$P_1=P_0-S_1$	*From Irrig 2*	P_1	S_1	P2	*From Irrig 2*	P2	S3	P3	*From Irrig 2*	P3	S4	P4
L	105	15	15	90	30	90	30	90	30	90	30	90	30	90	30	90
M	105	30	30	75	60	75	60	75	60	75	60	75	60	75	60	75
H	105	25	25	80	50	80	50	80	50	80	50	80	50	80	50	80

Notes:

Assumes the top layer retains 50% of water absorbed during irrigation No 2 with 50% being lost via evaporation etc

Assumes second and subsequent layers has not lost any of the water gained from first irrigation

Study of Table 4.6 shows:

After the first irrigation:

- The top layer (0 – 250mm) for all three soils has reached FC in that the amount of water stored equals the amount of water the layer can store and there is a balance of water left over to percolate to the second layer.
- The second layer of the sandy (L) and heavy (H) soils also reaches FC and a balance of water percolates down into layer 3; 45mm and 5mm respectively. The second layer of the medium soil (M) has reached about 75% of FC with 45mm stored out of a total requirement of 60mm.
- The third layer of the sandy soil also reaches FC and a total of 15mm percolates down into the fourth layer. A very small amount of moisture, 5mm, enters the top of the third layer of the heavy soil and no moisture at all reaches layer 3 of the medium soil.
- The fourth layer of the sandy soil reaches about 50% of FC as it receives 15mm percolation from above, but it needs another 15mm to be at FC.

After the second irrigation:

- The first three layers of all three soil types has reached FC and there is moisture left over to percolate to the fourth layer
- The fourth layers of the (L) and (H) soils has reached FC and there is moisture left over to percolate to the deep subsoil – a fifth layer if you like
- The fourth layer of the (M) soil has received 15mm of moisture whilst it can hold 60mm so it has reached 25% of FC

After the third irrigation:

- The fourth layer of all three soil types reaches FC, and
- There is moisture remaining in this layer to percolate deeper to flush the lower layers or join-up with the water-table

After the fourth irrigation:

- All three soils are at FC in all four layers and considerable amounts of water are percolating to depth in the leaching process.

In addition, further data regarding the amount of water that has passed through the layers can be extracted from this table. If we limit the study to the top (0 – 250mm) layer of the medium (M) soil:

Table 4.5 Water passing through Layer 1 of Medium Soil

	Amount of water applied (mm)	**Amount of water entering the soil (mm)**	**Amount of water "passing through" Layer 1 (mm)**
Irrigation 1	150	105	45
Irrigation 2	150	105	75
Irrigation 3	150	105	75
Irrigation 4	150	105	75
Total water passing through	600	420	270

If this was the situation with the most heavily salinised soil detailed in Table 4.2 where the depth of leaching water (Dlw) was calculated at 625mm it is clear that this soil has not yet reached anywhere near the leaching that is required and approximately another 5 leachings might be needed. However, the soil will be well on the way to recovery in the upper layers but the salt concentration has most likely increased significantly in the lower layers.

5 WATER QUALITY

The quality of the water that is used for irrigation will, with prolonged use, determine the salinity of the soil and the level of sodium adsorbed onto the soil exchange complex; that is it will effect the exchangeable sodium percent (ESP).

No long discussion is presented here; all that is done is give some of the normally accepted classification systems used for water quality.

Table 5.1 Effect of Irrigation Water Quality on Soil Salinity

Water Salinity ECw (dS/M)	Effect on Soil Salinity	Notes
<0.75	None or little	Basically safe to use for irrigation with little effect on the soil
0.75 – 3.0	Moderate	Can be used for irrigation but with careful management, possible use of amendments (gypsum) and adequate leaching fraction
>3.0	High	Not recommended for use in irrigation

Source: FAO, 24 1977

Table 5.2 Irrigation Water Classes

Irrigation water Salinity Hazard Class	ECw (dS/m)	Description & Notes
C1 Low salinity water	<0.25	Can be used for most crops on most soils with low chance of developing a salinity problem. Some leaching required but this would happen under normal, well managed irrigated agriculture
C2 Medium salinity class	0.25 – 0.75	Can be used if a moderate amount of leaching occurs. Crops with moderate tolerance to salinity can be cultivated without special measures for control of salinity
C3 High salinity class	0.75 – 2.25	Cannot be used on soils with restricted drainage. Even with adequate drainage special management for salinity control will be required and crops with high tolerance to salinity used.
C4 Very high salinity class	>2.25	Not suitable for irrigated agriculture under normal circumstances. Soils must be very permeable (sandy), drainage must be good, irrigation water must be supplied in excess to provide excessive leaching and only very salt tolerant crops can be grown

Source: Bookers, 1991

6 UNITS / CONVERSIONS

6.1 USEFUL CONVERSION FACTORS AND FORMULAS

Various conversion factors have been used in this report. These are useful rule-of-thumb conversions and depend, when dealing with salinity, upon the type(s) of salt in the solution. The following conversions are most commonly used:

EC * 650 = ppm of salt in the solution. The same as total dissolved solids (TDS). Valid for the EC range 0.1 to 5.0 dS/m.

At EC greater than 5.0 then: EC * 800 = ppm of salt in solution.

EC * 10 = sum of cations (or anions) expressed in mmolc / l

Osmotic pressure (OP) = -0.36 *ECe (mixed salt solution)
= -0.28*ECe (gypsum solution)

6.2 UNITS OF MEASUREMENT

The salt content of soil and water has been expressed in various units in the past according to:

- concentration
- electrical conductivity and
- osmotic pressure.

The previous units of measurement have now been replaced by internationally agreed units (SI units) and the correlation between old and new units is given below.

Variable	Former Unit	New Unit
Electrical Conductivity	Millimho/centimetre (mmhos/cm)	DeciSiemen/metre (dS/m)
Concentration	Parts per million (ppm) Milliequivalents/100 grams (me/100g) Milliequivalents/litre (me/l)	Milligrams/kilogram (mg/kg) Millimolc/100 grams1 Millimolc/litre (mmolc/l)
Osmotic Pressure	Atmosphere or Bar	Pascal

1 Millimolc (mmolc) denotes millimoles per charge and is exactly the same as the older milliequivalent unit

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Appendix B Methods

B.1 GENERAL

In this section a short comparison is presented of some of the methods of calculating the volume of water required for leaching. Actual examples from previous "real" reclamation studies are used as they allow a comparison of the findings.

Planning for the reclamation of saline areas requires a reliable estimate of the quantity of water necessary to reduce soil salinity to a level where crops can be economically produced.

Workers dealing with saline land in many countries have measured the changes in salinity and alkali by applying measured quantities of water to soils under field conditions. Most of these trials involved the ponding of water on the surface of the soil and the use of rice as the reclamation crop. Soil sampling and analysis at regular intervals resulted in the preparation of leaching curves.

Soils of different textures usually have different permeabilities and so the amount of salt removed, per unit quantity of water, varied. The coarser textured soils required the least amount of water, followed by the loamy textured soils and the finest textured soils such as clays, the largest quantities. Ponding on the surface results in saturated flow through the soil and is less efficient in salt removal than intermittent application of water (Nielsen et. al., 1966). Various approaches for the calculation of the quantity of water needed for reclamation were considered.

B.2 LYSIMETER STUDIES

Bonifica (1986) carried out leaching tests in laboratory lysimeters (disturbed soil passing a 2mm sieve) and the depth of soil packed into the lysimeter was the same as the horizon depth of the profile studied. The laboratory results were compared with the results calculated from an empirical formula of the type:

$$V = (1.32ECe * SP - 0.4SP) * Ft/4$$

where:

- V - net volume of water required in m3/ha for leaching
- ECe - electrical conductivity of the soil saturation extract (dS/m)
- SP - soil saturation percentage
- 4 - salinity value (dS/m) to be reached
- Ft - multiplying factor relating to the leaching depth

The derivation of this formula is not stated although it does take account of the texture (as SP), the initial salt content (ECe), the final desired salinity (4dS/m) and the soil depth to be leached.

The equation is claimed to be valid for an initial ECe up to 20dS/m, the value V should be reduced by 30percent for the ECe range 20-40, 40percent between 40-60ECe and 50percent in excess of ECe 60. These reductions were based on a comparison of the lysimeter data with their empirical equation.

3 SALT LEACHING CURVES (PONDED WATER APPROACH)

The leaching graphs were used to determine the amount of water needed to reduce the overall profile salinity down to 80cm (reclamation depth used by Bonifica, To do this it was necessary to calculate the weighted mean of the salinity throughout each profile to a depth of 80cm.

An example is a soil with weighted mean salinity (ECe) down to 80cm is 30.5. From leaching graph for a silty clay loam the value for Dlw/Ds is 1.4. Ds is the soil depth to be reclaimed and, in this case, is 80cm.This means that to reclaim this silty clay loam soil to a depth of 80cm requires a total amount of water (Dlw) equal to 1.4*80 or 112cm that has to pass the 80cm depth.

B.4 RULE-OF-THUMB APPROACH

Reeve and Fireman (1967) stated that when Dlw/Ds = 0.5 about 50 percent of the salt is removed over the depth Ds and when Dlw/Ds = 1.0 then 80 percent of the salt is removed over the depth Ds. These observations apply to medium textured soils with a little less water needed for coarser textures (90 percent salt removed) and a little more (70 percent salt removal) for finer textures.

All these calculations are based on keeping the soil surface more or less flooded during leaching. Salt removal is not efficient under these conditions and the introduction of intermittent irrigation, where feasible, results in the need for less water.

B.5 INTERMITTENT IRRIGATION APPROACH

Hoffman (1980) generated the following empirical leaching formula, based on field data obtained from various parts of the world:

$C/C_o = k/Dlw * Ds^{-1}$

Rearranging this formula:

$Dlw = k * Ds * C_o/C$

This formula was derived from leaching tests using the ponded water technique and k varied according to the soil texture. However Hoffman (1980) also showed that for intermittent irrigation (using an irrigation gift between 50 and 100mm per irrigation with irrigations about a week apart) then k becomes 0.1 for all textures.

Table B.1 presents results for the amount of water required for leaching the same soil calculated by the various methods presented above.

Table B.1 Results of Dlw by various methods

Project	Site	Depth cm	Texture		ECe initial	ECe leached	Dlw_p Bonifica m^3/ha	Dlw_p* Curves m^3/ha	Dlw_p Thumb-rule m3/ha	Dlw_i Hoffman m^3/ha
			class	group						
Seleim	9	0-20	L	M	7.3	3.5	2400	9600	12000	9200
		20-80	SiL	M	61.5	4.1	37600			
Wadi Qaab	2	0-20	CL	H	8.2	4.0	2800	11200	12000	9600
		20-40	SiL	M	46.1	4.4	17200			
		40-80	SiCL	H	33.7	3.6	20400			
Pilot Farm	3	0-20	SL	L	18.1	4.4	5000	nd	8000	6000
		20-80	SL	L	55.4	3.7	32400			

* *Calculated from leaching curves according to texture*

Subscript p refers to the ponded water case; subscript i refers to intermittent irrigation case

B.6 CONCLUSIONS

There is good agreement between the curve and rule of thumb estimates using the ponded water scenario. The Bonifica estimates from their lysimeter studies are much too high in comparison the other determinations.

The estimate using the Hoffman formula gives values of the same order of magnitude as curve and rule of thumb albeit somewhat lower. Water supplies are likely to be restricted and the ponded water scenario should not be considered. Water applications should be in small basins that allow up to 10cm per irrigation. This accords well with the Hoffman intermittent leaching regime and so this formula will be used to estimate leaching water requirements for the soils of the Study Areas.

Appendix C Laboratory Techniques

The spatial variability in salt concentration, encountered in many ultra saline soils, poses sampling, analytical, interpretation and classification problems. Most problems revolve around the interpretation of an alkali soil.

C.1 DIRECT DETERMINATION OF ESP

The exchangeable sodium percentage (ESP) may be determined directly by measurement of exchangeable sodium and the cation exchange capacity. The determination of exchangeable sodium in a highly saline soil is extremely difficult and the result is subject to large errors. In addition the ESP requires the measurement of two parameters, both of them time consuming, somewhat tedious and requiring technical skills of a high order.

However, none of the soils under study are expected to be “highly” saline.

C.2 INDIRECT DETERMINATION USING THE SAR - ESP RELATIONSHIP

Many laboratories take the analytically easier option of measurement of the soluble cations in the saturation extract and calculation of the SAR, followed by use of the USDA (1956) SAR-ESP relationship to obtain the ESP. This relationship is only valid up to a SAR of 40. Use of the formula above this value often results in misleadingly high values for the ESP. In practice, as the salt is removed, the ESP reduces and the very saline soil water maintains permeability during the leaching process.

However, none of the soils under study are expected to have high SAR values.

C.3 PRE-WASHING

A more realistic assessment of sodicity may be provided by washing the soil sample prior to calculating its ESP or SAR. For any soil sample that has a pHs of 9.0 or more, first measure the pHp. Then, where pHp is 9.0 or more, wash the soil with distilled water until the wash water has an EC of 4.0 to 5.0 dS/m (but not less than 4.0) and then determine ESP by SAR or traditional exchangeable sodium and CEC methods.

Note, do not assume a value for CEC according to clay content.

For calculating any gypsum requirement, needs should be based on the SAR (ESP) determined when excess soluble salts have been washed out of the soil (USDA, 1975).

C.4 FACTORS TO THINK ABOUT

Soil pH is depressed in the presence of salts. Also soil pH is increased by exchangeable sodium (represented by the SAR). Therefore there are two competing influences operating.

Soil pH increases with an increase in the soil water ratio, due to hydrolysis of sodium from the exchange complex, therefore pHp is always less than pH 1:5. The difference between the pH determinations can be considerable.

Generally hydrolysis is more marked in sandy soils that have a poor buffering capacity compared to loams and clays.

It is difficult to prepare a saturation paste with sands and the SP derived is often too high; this results in a pHp somewhat higher than it should be. USDA (1956) recognised this problem and recommends an alternative termed the twice saturation extract. The method is tedious and not often used.

Appendix D Tools Developed for use in Reclamation

The tools are spreadsheets to enable calculations to be done quickly and to allocate ratings to various soil parameters. These are all MS Excel spreadsheets and easy to use as very little data needs to be entered.

As the tools have been used previously in this report no in-depth discussion is presented in this section.

The introduction page, showing formula and definitions is given in each case as is an example of output from the tool.

D.1 Estimation of Leaching Water Requirement

LEACHING WATER REQUIREMENT DETERMINATION

Based on formula of Hoffman (1980) Dlw = k*Ds*ECo/EC

Where:

Dlw	Depth of leaching water (mm)
Ds	Depth of soil layer (mm)
ECo	Electrical conductivity of soil needing reclaimed (dS/m)
EC	Desired electrical conductivity once soil is reclaimed (dS/m)
k	Constant

Refer: Salinity & Reclamation *A.A.Hutcheon October 2005*

Irrigation Leaching Progress *A.A.Hutcheon October 2005*

Enter data	*Initial*	*Initial EC*	Depth of Soil		*Desired EC*	*Desired*		Leaching Water Required	
Site / Sample Number	**ECo dS/m**	**Salinity class**	**Ds (mm)**	**Constant "k"**	**EC dS/m**	**Salinity class**	**ECo/EC**	**Dlw (mm)**	**Dlw m3/ha**
January									
Aceh Utara - max	100	SC6	250	0.1	4	SC2	25.0	625	6250
Aceh Utara - min	44	SC5	250	0.1	4	SC2	11.0	275	2750
Bereuen - max	6.5	SC2	250	0.1	4	SC2	1.6	41	406
Pidie - max	10	SC3	250	0.1	4	SC2	2.5	63	625
Pidie - min	5	SC2	250	0.1	4	SC2	1.3	31	313
March									
Aceh Utara - max	17	SC4	250	0.1	4	SC2	4.3	106	1063
Aceh Utara - min	7	SC2	250	0.1	4	SC2	1.8	44	438

D.2 Leaching Water Requirement – Bonfica Formula

Volume of Water for Reclamation **Bonfica Formula**

Formula: V = (1.32ECe*SP - 0.4SP) * Ft / ECt

V net volume of water required in m3/ha [cubic metres / hectare] for leaching
SP saturation percentage of the soil
ECe initial electrical conductivity of the soil saturation extract (dS/m)
ECt target electrical conductivity to be reached (dS/m)
Ft "factor" relating to the leaching depth

Sample No	Depth to be leached (cm)	ECe (dS/m)	ECt (dS/m)	Texture	SP *	V (m^3/ha)	V Adjusted (m3/ha)
Add Data	*Add Data*	*Add Data*	*Add Data*	*Add Data*	*Add Data*	*Automatic*	*Automatic*
1	25	100	4	L	35	28788	14394
2	25	44	4	SiL	40	14420	5768
3	25	6.5	4	CL	44	2250	2250
4	25	10	4	CL	44	3520	3520
5	25	5	4	S	30	1163	1163
6	25	17	4	SCL	35	4821	4821
7	25	7	4	SL	32	1768	1768

The same data as was used in conjunction with the tools in Section D.1 and D.3 has been used in this example.

However, values for SP were not available and “guestimates” were used on the basis that SP normally ranges from 30 – 45%.

D.3 Leaching Water Requirement

LEACHING REQUIREMENT (LR) CALCULATION

Calculate the LR from: - Salinity of water used for leaching, and
- Salinity of the soil being leached

Formula: LR = ECw / (5*ECe - ECw)

ECw EC (dS/m) of leaching water
ECe EC (dS/m) of soil layer

Sample	ECw dS/m	ECe / dS/m	LR
March data			
Aceh Utara - max	4	100	0.01
Aceh Utara - min	4	44	0.02
Bereuen - max	4	6.5	0.14
Bereuen - min	4	1	
Pidie - max	4	10	0.09
Pidie - min	4	5	0.19
May Data			
Aceh Utara - max	4	17	0.05
Aceh Utara - min	4	7	0.13
Bereuen - max	4	3.2	
Bereuen - min	4	0.1	
Pidie - max	4	2	
Pidie - min	4	0.2	

D.4 Irrigation Leaching Progress

IRRIGATION LEACHING PROGRESS

1 This spreadsheet allows the process of reclamation leaching to be followed as initial irrigation gift of 100mm is applied followed by subsequent similar gifts

2 Four layers of soil are considered within the top metre:
0 - 250mm The main planting / seed germination zone
250 - 500mm The root zone for slightly deeper rooting crops
500 - 750mm and The main root zone for many crops
750 - 1000mm The top part of the subsoil and often as deep as most crops root\

3 The system of irrigation / reclamation is "intermittant" and NOT continous flooding: that is there is a gap of a few days between each irrigation

4 The spreadsheet could be expanded to cover many irrigations / leaching water applications but it is presently only showing four

5 **Definitions / Codes Used**

S_1 amount of water (mm) stored in the 0 - 250mm (0 - 25 cm) layer
S_2 amount of water (mm) stored in the 250mm - 500 (25 - 50 cm) layer
P_0 depth of water entering the soil form the Irrigation Gift at Adopted Application Efficiency
P_1 amount of water percolating from the 0 - 250mm layer after storage to field capacity (FC)
P_2 amount of water percolating from the 250 - 500mm layer after storage to field capacity (FC)
Note: Percolating water (P_2, P_3 and P_4) contributes to the Dlw needed to reclaim the soil
Dlw Depth of Leaching Water (mm) needed for reclamation (*Refer Leaching Water Requirement.XLS*)

Refer **Salinity & Reclamatio** *A.A.Hutcheon October 2005*

Texture Group	Adopted AWHC (mm / m)	Adopted Application Efficiency (AE)	Irrigation Gift (mm)	Depth of water entering soil (mm)
L	120	0.7	150	105
M	240	0.7	150	105
H	200	0.7	150	105

The values in the boxes on the left can be changed for:

AWHC - change if actual and not estimated figures exist

AE - change if a better or poorer efficiency is established

Irrigation Gift - change if larger or smaller amounts of water are applied at each irrigation

FIRST IRRIGATION		Top Layer 0 - 250 mm			Second layer 250 - 500mm				Third layer 500 - 750mm				Fourth layer 750 - 1000mm			
Texture Group	Depth of water infiltrating (mm)	Layer can hold (mm)	Depth (mm) water stored	Balance in layer for percolation	Layer can hold (mm)	Layer receives (mm)	Depth (mm) water stored	Balance in layer for percolation	Layer can hold (mm)	Layer receives (mm)	Depth (mm) water stored	Balance in layer for percolation	Layer can hold (mm)	Layer receives (mm)	Depth (mm) water stored	Balance in layer for percolation
Formula	P_1	*Calc from AWHC*	S_1	$P_1=(P_1-S_1)$	*Calc from AWHC*	P_1	S_1	P2	*Calc from AWHC*	P2	S3	P3	*Calc from AWHC*	P3	S4	P4
L	105	30	30	75	30	75	30	45	30	45	30	15	30	15	15	0
M	105	60	60	45	60	45	45	0	60	0	0	0	60	0	0	0
H	105	50	50	55	50	55	50	5	50	5	5	0	50	0	0	0

Notes:

For the sandy soil this first irrigation will leach salts from the top 25 cm down into the 25 - 50cm layer and start leaching into the third layer

For the medium and heavy soils there is little leaching as the soil in layer 1 has just reached field capacity hence there is little to percolate to layer 2

This first irrigation is a pre-planting irrigation to start flushing salts out of the planting zone

SECOND IRRIGATION		Top Layer 0 - 250 mm			Second layer 250 - 500mm				Third layer 500 - 750mm				Fourth layer 750 - 1000mm			
Texture Group	Depth of water infiltrating (mm)	Layer Already holds (mm)	To reach FC need (mm)	Balance in layer for percolation	Layer Already holds (mm)	Layer receives (mm)	Depth (mm) water stored	Balance in layer for percolation	Layer Already holds (mm)	Layer receives (mm)	Depth (mm) water stored	Balance in layer for percolation	Layer Already holds (mm)	Layer receives (mm)	Depth (mm) water stored	Balance in layer for percolation
Formula	P_0	*50% of irrig 1*	S1	$P_1=P_0-S_1$	*From Irrig 1*	P_1	S_1	P2	*From Irrig 1*	P2	S3	P3	*From Irrig 1*	P3	S4	P4
L	105	15	15	90	30	90	30	90	45	90	30	105	15	105	30	90
M	105	30	30	75	45	75	60	60	0	60	60	0	0	0	0	0
H	105	25	25	80	50	80	50	80	5	80	50	35	0	35	35	0

Notes:

Assumes the top layer retains 50% of water absorbed during irrigation No 1 with 50% being lost via evaporation etc

Assumes second layer has not lost any of the water gained from first irrigation

THIRD IRRIGATION		Top Layer 0 - 250 mm			Second layer 250 - 500mm				Third layer 500 - 750mm				Fourth layer 750 - 1000mm			
Texture Group	Depth of water infiltrating (mm)	Layer Already holds (mm)	To reach FC need (mm)	Balance in layer for percolation	Layer Already holds (mm)	Layer receives (mm)	Depth (mm) water stored	Balance in layer for percolation	Layer Already holds (mm)	Layer receives (mm)	Depth (mm) water stored	Balance in layer for percolation	Layer Already holds (mm)	Layer receives (mm)	Depth (mm) water stored	Balance in layer for percolation
Formula	P_0	*50% of irrig 2*	S1	$P_1=P_0-S_1$	*From Irrig 2*	P_1	S_1	P2	*From Irrig 2*	P2	S3	P3	*From Irrig 2*	P3	S4	P4
L	105	15	15	90	30	90	30	90	30	90	30	90	30	90	30	90
M	105	30	30	75	60	75	60	75	60	75	60	75	0	75	60	15
H	105	25	25	80	50	80	50	80	50	80	50	80	35	80	50	65

Notes:

Assumes the top layer retains 50% of water absorbed during irrigation No 2 with 50% being lost via evaporation etc

Assumes second and subsequent layers has not lost any of the water gained from first irrigation

FOURTH IRRIGATION		Top Layer 0 - 250 mm			Second layer 250 - 500mm				Third layer 500 - 750mm				Fourth layer 750 - 1000mm			
Texture Group	Depth of water infiltrating (mm)	Layer Already holds (mm)	To reach FC need (mm)	Balance in layer for percolation	Layer Already holds (mm)	Layer receives (mm)	Depth (mm) water stored	Balance in layer for percolation	Layer Already holds (mm)	Layer receives (mm)	Depth (mm) water stored	Balance in layer for percolation	Layer Already holds (mm)	Layer receives (mm)	Depth (mm) water stored	Balance in layer for percolation
Formula	P_0	*50% of irrig 2*	S1	$P_1=P_0-S_1$	*From Irrig 2*	P_1	S_1	P2	*From Irrig 2*	P2	S3	P3	*From Irrig 2*	P3	S4	P4
L	105	15	15	90	30	90	30	90	30	90	30	90	30	90	30	90
M	105	30	30	75	60	75	60	75	60	75	60	75	60	75	60	75
H	105	25	25	80	50	80	50	80	50	80	50	80	50	80	50	80

Notes:

Assumes the top layer retains 50% of water absorbed during irrigation No 2 with 50% being lost via evaporation etc

Assumes second and subsequent layers has not lost any of the water gained from first irrigation

D.5 Laboratory Data Summary

This tool has not been used as yet simply as there are no data to hand to import into the spreadsheet. The tool is for summarising standard laboratory data and is used to assist in identifying possible nutrient deficiencies and to allocate a classification of the amount of the nutrient or element is present in the soil – based on FAO. If the soils have data on aluminium it also calculates possible liming requirements.

Laboratory Data Summary

Topsoils											Exchangeables							(Element/CEC) x 100			
Series	No of	Depth	pH	pH	pH	Avail P	Avail K	Org C	Total N	C:N	meq / 100g							Mg	K	Al	BS
	Samples	Range	H2O	KCl	diff	ppm	ppm	%	%		Ca	Mg	K	Na	TEB	Al	CEC	Sat%	Sat%	Sat%	%
Lama	1	0 - 20	6.39	5.24	1.15	51.50	81.00	2.00	0.12	17	11.16	1.14	0.43	0.01	12.74	2.00	11.98	10	4	17	106
		Mean	6.39	5.24	1.15	51.50	81.00	2.00	0.12	17	11.16	1.14	0.43	0.01	12.74	2.00	11.98	10	4	17	106
		Rating	Sli Acid	ND	ND	High	ND	Mod	Low	Mod	High	Low	Mod	V Low	Mod	High	Low	V Low	V Low	Mod	V High
Baru	2	0 - 21	6.28	4.72	1.56	82.31	87.13	2.60	0.16	16	9.78	1.79	0.50	0.05	12.12	1.00	12.96	14	4	8	94
		Mean	6.28	4.72	1.56	82.31	87.13	2.60	0.16	16	9.78	1.79	0.50	0.05	12.12	1.00	12.96	14	4	8	94
		Rating	Sli Acid	ND	ND	High	ND	Mod	Low	Mod	Mod	Mod	Mod	V Low	Mod	Mod	Low	ND	V Low	Low	V High
Kosong	2	0 - 22	6.34	4.64	1.70	19.16	9.20	0.84	0.09	9	6.46	1.41	0.14	0.06	8.07	1.00	9.43	15	1	11	86
		Mean	6.34	4.64	1.70	19.16	9.20	0.84	0.09	9	6.46	1.41	0.14	0.06	8.07	1.00	9.43	15	1	11	86
		Rating	Sli Acid	ND	ND	Mod	ND	Low	V Low	V Good	Mod	Low	Low	V Low	Mod	Mod	Low	ND	V Low	Mod	V High
Berat	8	0 - 22	6.15	5.01	1.14	77.43	153.68	2.73	0.20	14	6.60	0.85	0.44	0.03	7.92	1.00	11.66	7	4	9	68
		Mean	6.15	5.01	1.14	77.43	153.68	2.73	0.20	14	6.60	0.85	0.44	0.03	7.92	1.00	11.66	7	4	9	68
		Rating	Sli Acid	ND	ND	High	ND	Mod	Mod	Good	Mod	Low	Mod	V Low	Mod	Mod	Low	V Low	V Low	Low	High
Hilang	1	0 - 20	6.31	5.50	0.81	229.57	245.19	1.80	0.16	11	7.85	1.69	1.20	0.04	10.78	1.00	10.26	16	12	10	105
		Mean	6.31	5.50	0.81	229.57	245.19	1.80	0.16	11	7.85	1.69	1.20	0.04	10.78	1.00	10.26	16	12	10	105
		Rating	Sli Acid	ND	ND	V High	ND	Mod	Low	Good	Mod	Mod	V High	V Low	Mod	Mod	Low	ND	ND	Low	V High

To use this sheet immediately save with a new name - survey area - on your own PC or in the relevant directory on the server
Add data to the relevant white boxes on the "Data + Ratings" sheet
On the "Data + Ratings" sheet the yellow boxes will fill with means, ratios and ratings
Suggested "Lime Requirements" will appear automatically in that sheet
pH versus ASP will automatically plot in the "pH vs ASP" sheet

Topsoils											Exchangeables							(Element/CEC) x 100				Cation Ratios		Cation Ratios	
Series	No of	Depth	pH	pH	pH	Avail P	Avail K	Org C	Total N	C:N		meq / 100g						Mg	K	Al	BS				
Site	Samples	Range	H2O	KCl	diff	ppm	ppm	%	%		Ca	Mg	K	Na	TEB	Al	CEC	Sat%	Sat%	Sat%	%	Ca/Mg	Rating	Mg/K	Rating
Aceh Utara	1	0 - 25	6.60	6.00	0.60	0.00	22.00	9.00	0.10	90	5.00	1.00	1.00	1.00	8.00	0.00	15.00	7	7	0	53	5.00	Mg sli deficient	1.00	Mg deficient
		Mean	6.60	6.00	0.60		22.00	9.00	0.10	90	5.00	1.00	1.00	1.00	8.00	0.00	15.00	7	7	0	53	5.00	Mg sli deficient	1.00	Mg deficient
		Rating	Neutral	ND	ND		ND	V High	Low	V Poor	Mod	Low	High	High	Mod	ND	Mod	V Low	V Low	ND	Mod				
																0.00				####					
		Mean			######					######					######	0.00		######	####	####	######	#######	#VALUE!	######	#VALUE!
		Rating														ND				###					
																0.00				####					
		Mean			######					######					######	0.00		######	####	####	######	#######	#VALUE!	######	#VALUE!
		Rating														ND				###					
																0.00				####					
		Mean			######					######					######	0.00		######	####	####	######	#######	#VALUE!	######	#VALUE!
		Rating														ND				###					
																0.00				####					
		Mean			######					######					######	0.00		######	####	####	######	#######	#VALUE!	######	#VALUE!
		Rating														ND				###					
																0.00				####					
		Mean			######					######					######	0.00		######	####	####	######	#######	#VALUE!	######	#VALUE!
		Rating														ND				###					
																0.00				####					
		Mean			######					######					######	0.00		######	####	####	######	#######	#VALUE!	######	#VALUE!
		Rating														ND				###					
																0.00				####					
		Mean			######					######					######	0.00		######	####	####	######	#######	#VALUE!	######	#VALUE!
		Rating														ND				###					
Total	1																								
Overall mean for topsoils			########	######	######		######	#######	#######	######	######	######	######	######	######	0.00	####	######	####	####	######	#######	#VALUE!	######	#VALUE!
Overall ratings for topsoils			#VALUE!	####	####		####	#####	#####	####	####	####	####	####	####	ND	###	####	###	###	####				
	NB	If there are NO AVAILABLE Values for "Al" leave the entered value (0.001) as shown above																							