Dispersive Soils and Their Management: A technical reference manual

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DISPERSIVE SOILS *and* *their* MANAGEMENT

Technical Reference Manual

Sustainable Land Use
Department of Primary Industries and Water

Tasmania
Explore the possibilities

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PURPOSE OF THIS DOCUMENT

Currently, there is little locally relevant or available information on the management of dispersive soils in urban and peri-urban environments. Issues associated with dispersive soils and their management are not adequately addressed in planning schemes, building codes or the development approval process. This document seeks to provide a summary of the available science and experience gained with the management of dispersive soils and tunnel erosion in Tasmania. It is expected this document will have relevance for a range of stakeholders including, professionals in the building and construction industry, local government, affected landholders and natural resource managers. It is important to acknowledge that advice provided in this document results from a process of expert opinion and field observation, rather than rigorous scientific study or an established body of locally relevant literature. This document will require updating as new information becomes available.

The purpose of this document is to,

» Raise awareness of the risks associated with development and construction on dispersive soils.

» Reduce the incidence of tunnel erosion and environmental harm resulting from disturbance of dispersive soils in Tasmania.

» Indicate the types of environments in which tunnel erosion and dispersive soils occur.

» Review chemical and physical analytical techniques used for identifying dispersive soils.

» Identify risks associated with traditional construction techniques on dispersive soils.

» Outline low-risk options for construction and development on dispersive soils.

» Review methods for repairing tunnel erosion in peri-urban environments.

1.0 INTRODUCTION: WHY DISPERSIVE SOILS AND TUNNEL EROSION ARE AN ISSUE

» Dispersive soils and tunnel erosion have been found in all municipalities in southern Tasmania, and several locations in northern Tasmania.

» In recent years, urban expansion has occurred in areas known to contain dispersive soils.

» Tunnel erosion in dispersive or sodic soils mostly occurs in areas with
  - Soils derived from Triassic sandstone or Permian mudstone.
  - Deep sedimentary soils.
  - North facing slopes.
  - Slopes over 10 degrees.
  - Drainage lines.
  - Areas in which vegetation, soils or local hydrology have been disturbed.

» Tunnel erosion has the potential to result in considerable damage to infrastructure (including dwellings) and the environment.

» The location or extent of dispersive soils has not been specifically mapped in Tasmania.

» Existing soil maps and tunnel erosion hazard maps are unsuitable for land use planning and infrastructure development.

Dispersive soils and tunnel erosion occur in all municipalities in southern Tasmania, as well as parts of the Northern Midlands, Tamar Valley and Break O'Day municipalities. In recent years, urban expansion on dispersive soils has increased the incidence of infrastructure damage and environmental harm resulting from tunnel erosion. Unlike other forms of erosion, tunnel erosion results from a combination of both chemical and physical processes, which makes its control and repair difficult. Management of tunnel erosion is focused on both the prevention of further tunnel erosion and improved repair and management of existing tunnel affected land.

1.1 ENVIRONMENTS IN WHICH DISPERSIVE SOILS AND TUNNEL EROSION OCCUR

Crouch (1976) identified that landscapes which were predisposed to tunnel erosion had;

» A seasonal or highly variable rainfall combined with high summer temperature.

» Cracking of surface soils due to desiccation.

» A reduction or detrimental change in vegetative cover.

» A relatively impermeable layer in the soil profile.

» Sufficient slope to create sub-surface flow.

» A dispersible soil layer.

In Tasmania, tunnel erosion is commonly associated with dispersive subsoils derived from Triassic sandstone, or Permian mudstone (Colclough 1978, Doyle and Habraken 1993). However tunnel erosion is also known to occur on dispersive soils derived from Jurassic Dolerite (Bruny Island, Dunalley and Orielton) and Lower Carboniferous – Upper Devonian granites (Elephant Pass). Tunnel erosion mostly occurs on moderately steep (>10°) north or north-east facing slopes in areas with less than 650 mm annual rainfall. Tunnel erosion is less common in shallow soils or soils containing a high proportion of stones (exceptions exist, Figure 1a) and areas with greater than 800mm rainfall.

Figure 1a & b. Exceptions always exist. (a) Tunnel erosion in shallow stony ground located on a side slope away from drainage lines, Brighton. (b) Tunnel erosion in a mature forest, on dispersive soils derived from Triassic Sandstone, Middleton. Tunnel erosion existed prior to felling of trees in the foreground.

The nature and extent of tunnel erosion appears to differ between soil types. In soils derived from Permian sediments, tunnel erosion is usually confined to a single narrow 'slot' often within a drainage line. In soils derived from Triassic sediments, tunnels often have multiple branches and frequently occur on hillslopes as well as drainage lines. While tunnel erosion usually results from some form of disturbance, in a few instances tunnel erosion has occurred in otherwise undisturbed environments (Figure 1b).

1.2 TUNNEL EROSION HAZARD MAPPING

The location and extent of tunnel erosion in Tasmania has not been specifically mapped or investigated, however land system mapping indicates that approximately 103,000 ha of private freehold land has a tunnel erosion hazard (Grice 1995). Figure 2, the 'Location of tunnel erosion prone dispersive soils (sodic soils or sodosols) in Southern Tasmania (DPIWE 2004)' map has been created by modifying the Soil Orders Map of Tasmania 1: 500,000, (DPIWE 2004) to reveal the location of sodosols (soils with more than 6% sodium in the subsoil) as a predictor of dispersive soils. Figure 3 the 'Map of land systems containing areas of tunnel erosion on private freehold land in Southern Tasmania' has been generated from state-wide land systems mapping in which combinations of soil, geology and climate have been inferred to reveal areas which have an elevated likelihood that tunnel erosion may occur (Grice 1995). Note: neither of these maps indicate the actual location or extent of dispersive soils or tunnel erosion.

Tunnel erosion hazard maps in Figures 2 and 3 (pages 9-10) cannot be used for land use planning or making decisions on soil suitability for sub-division. Note that some areas indicated to have a dispersive soil or tunnel erosion hazard differ between the two maps. These discrepancies are expected, and result from differences in how the two maps were produced. Landuse planning, sub-division works and site development require field inspections and large scale soil mapping at 1:5,000 – 1:10,000 scale.

A local example of larger scale land suitability mapping for residential development was conducted in the Brighton municipality to identify soils which were unsuitable for urban development (Figure 4) (Cumming 2003). Similar landuse and erosion surveys have been used to quantify risk associated with urban development on erosion prone loess soils in the Port Hills, Christchurch, New Zealand (Trangmar 2003).

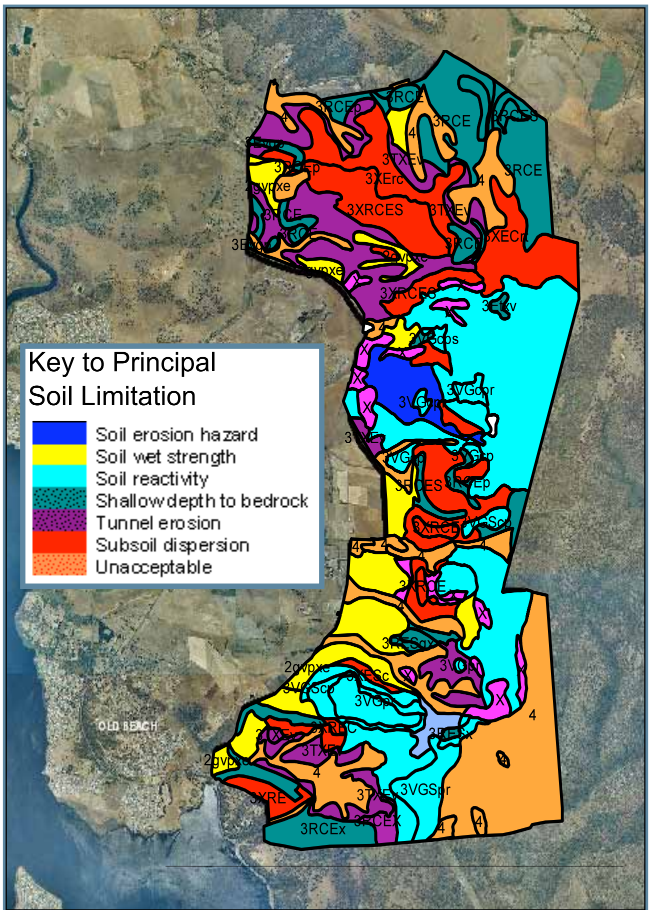

Figure 4. 1:10,000 Brighton Land Use Suitability Map (Cumming 2003).

Cumming (2003) notes '*The map is reliable only at the scale published, and must not be enlarged…..*'

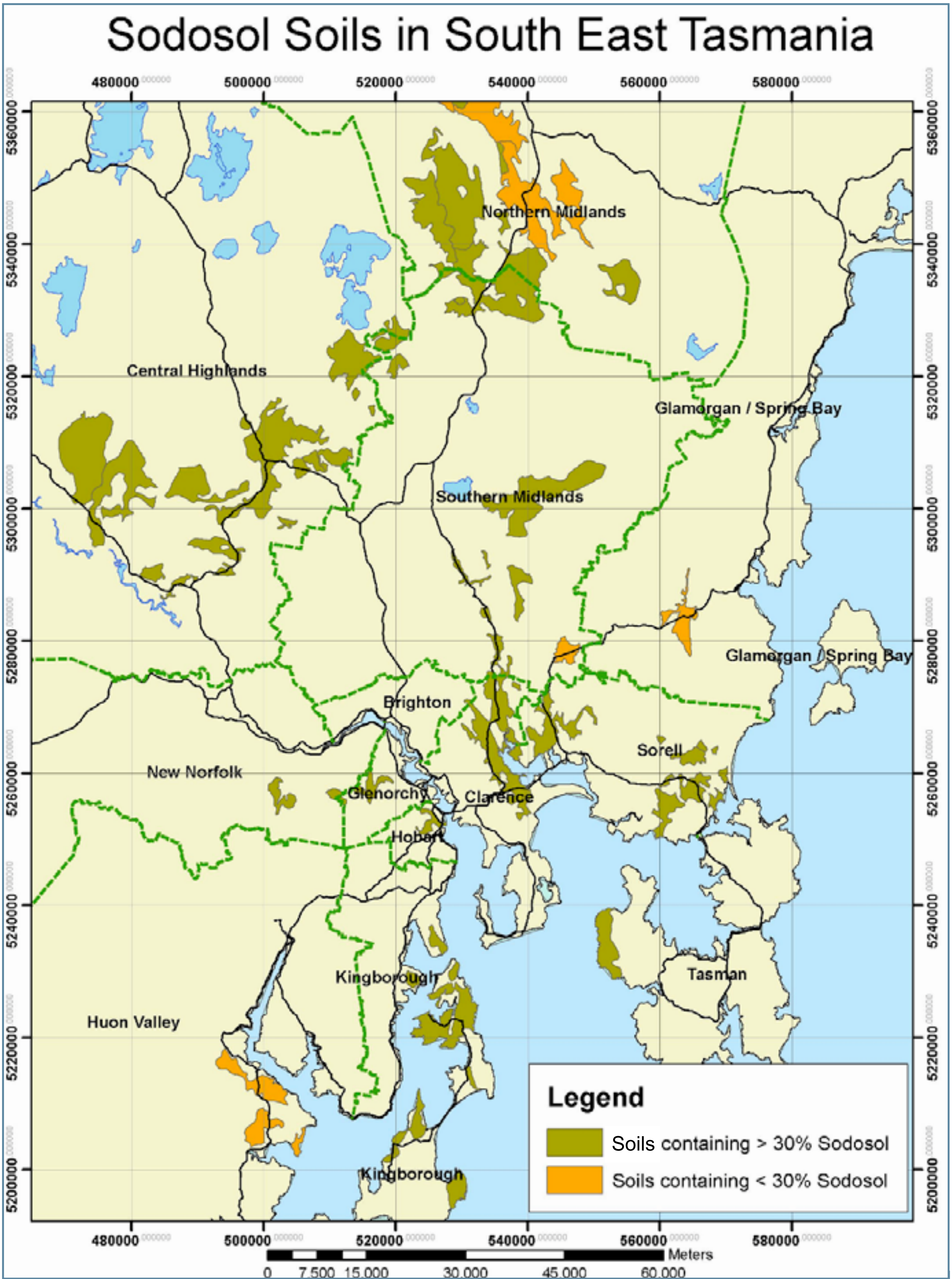

Figure 2. Location of tunnel erosion prone dispersive soils (sodic soils or sodosols) in Southern Tasmania (DPIWE 2004).

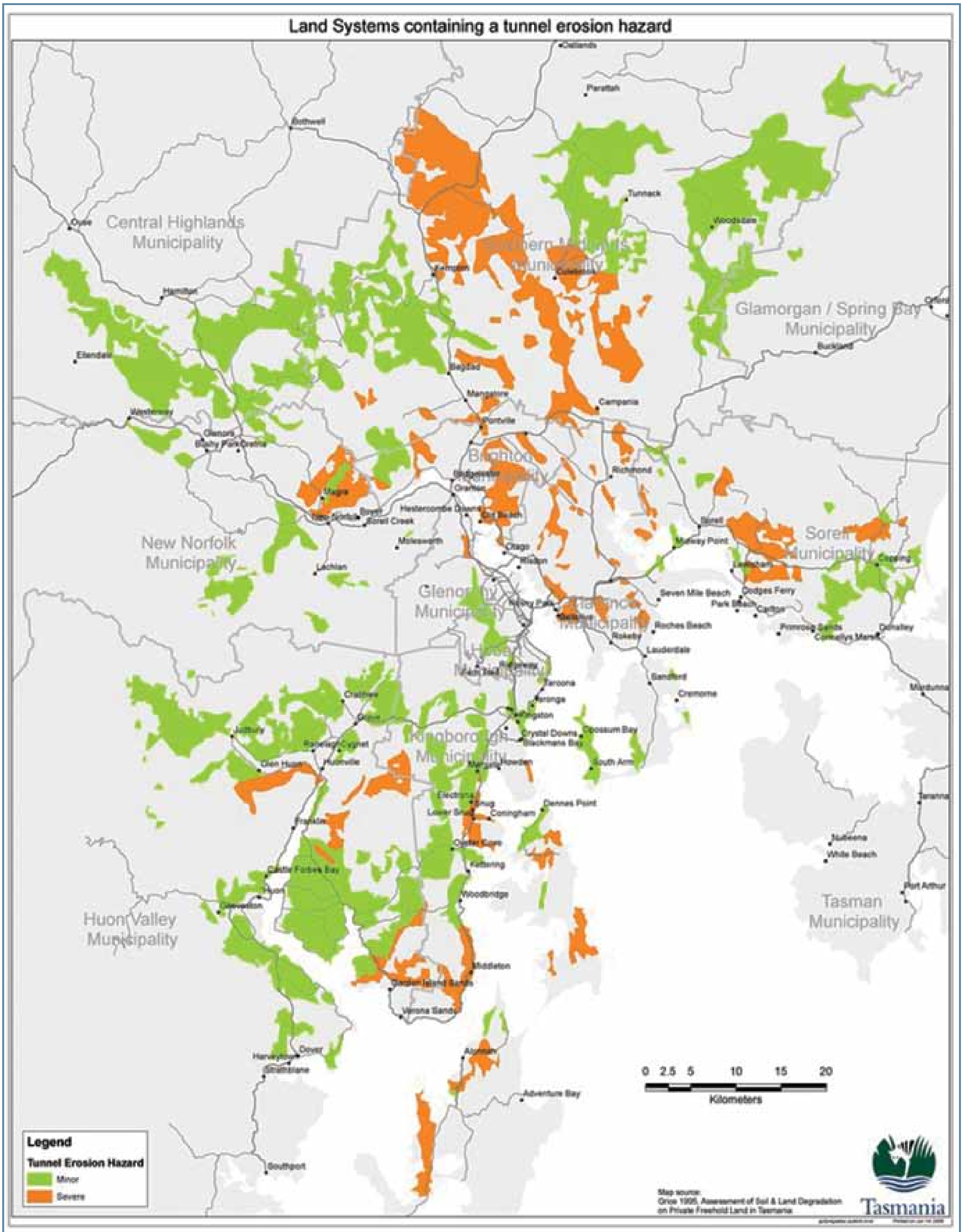

Figure 3. Map of land systems containing areas of tunnel erosion on private freehold land in Southern Tasmania (based on Grice 1995).

2.0 UNDERSTANDING DISPERSION AND THE EROSION PROCESS

SODIC SOILS AND DISPERSION

- Dispersion results from the presence exchangeable sodium between clay platelets.
- Dispersion results in the swelling of clay platelets and collapse of clay aggregates.
- Dispersion is often seen as 'muddy' or 'milky' water in dams and surface water.
- Dispersion only occurs in non-saline water or rainwater.

TUNNEL EROSION RESULTS FROM

- Both chemical and physical processes.
- Dispersion of clay subsoils.
- Sodic or dispersive subsoils coming into contact with fresh water (rain, runoff etc).
- Soil cracks and pores which enable runoff and dispersed clays to flow through the soil.
- Intense rainfall events on dry cracked soil, usually at the end of summer.
- Loss of topsoil through erosion or excavation which exposes dispersive soils to rainfall.
- Hydraulic disturbance such as vegetation removal or creation of runoff.

2.1 SODICITY AND DISPERSION

Tunnel erosion mostly occurs in dispersive soils (Vacher *et al.* 2004) which typically contain greater than 6.0 % exchangeable sodium (ESP). These soils are known as sodic soils or Sodosols (Isbell 2002), or in the past may have been referred to as Solodic, Solonetz or Solodized – solonetz (Doyle and Habraken 1993). Other soils such as Vertosols, Kurosols and Kandosols may also contain sodic or dispersive soil layers.

When a sodic soil comes into contact with non-saline water, water molecules are drawn in-between the clay platelets causing the clay to swell to such an extent that individual clay platelets are separated from the aggregate, this process is known as dispersion (Figure 5, van de Graaff & Patterson 2001, Nelson 2000). When small aggregates are placed in a dish of distilled water they appear to 'dissolve' into a milky ring or halo. This milky ring is the ejected clay platelets floating away from the clay aggregate. Dispersed platelets are often so small that they remain forever in suspension, which explains why dams constructed from dispersive clays never settle and always appear 'muddy' or 'milky'.

While sodic soils are generally dispersive, it is important to acknowledge that not all sodic soils disperse, and that not all dispersive soils are sodic (Sumner 1993). Factors such as silt and high magnesium content may induce non-sodic soils (ESP <6%) to disperse, while organic matter, clay mineralogy, acidity, and high iron content may prevent sodic soils (ESP >6%) from dispersing (Raine and Loch 2003, Rengasamy 2002). In southern Tasmania degraded Kurosols are known to be dispersive despite having less than 6.0 % ESP (Doyle pers. comm.). In addition, soils which are both saline and sodic do not disperse or behave like sodic soils until the salt is leached from the soil profile, usually following subsurface drainage (Rengasamy and Olsson 1991).

In slightly saline water, or water with a moderate electrolyte (salt) concentration, sodic soils swell, but generally don't disperse. The clay platelets remain intact. The presence of salts within the soil water reduces the osmotic gradient between the outside and inside of the clay platelets preventing the ultimate stage of swelling leading to dispersion (Nelson 2000). Maintenance of salts within the soil water is one of the most important mechanisms by which sodic soils are protected from dispersion and development of tunnel erosion.

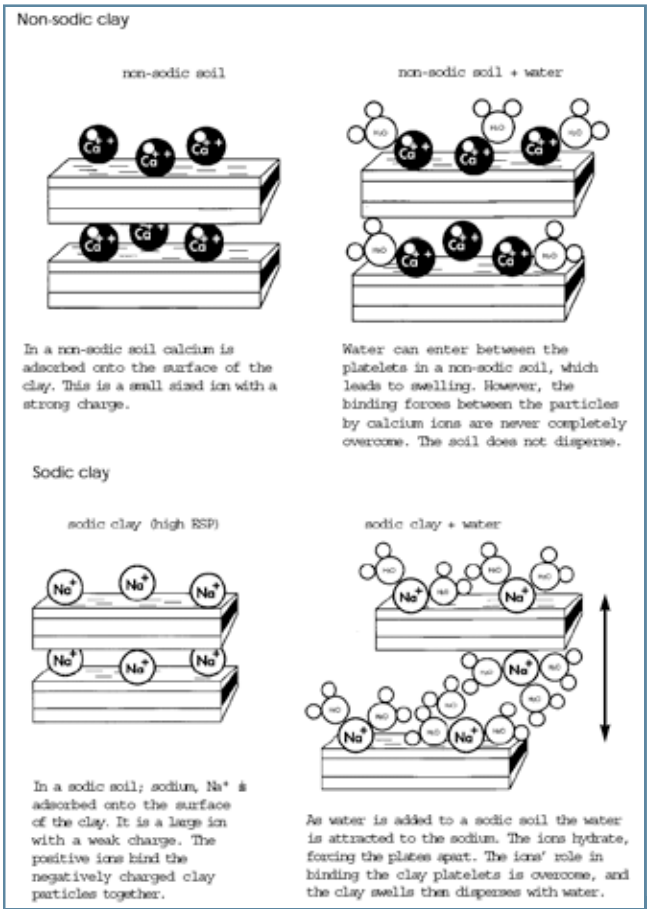

Figure 5. Behaviour of non sodic and sodic soils in water. (Anon 1999a).

2.2 TUNNEL EROSION

Tunnel erosion results from a complex interaction of chemical and physical processes associated with clay dispersion, mechanical scouring, entrainment and mass wasting. Observation indicates that in Tasmania, tunnel erosion usually starts as a result of rainfall coming into contact with dispersive subsoil following,

- Loss of topsoil ie excavation or erosion.
- Surface soil cracking due to desiccation (drying).
- A change in hydrology or generation of runoff.
- And occasionally formation of rabbit burrows or old root holes.

Once subsoil clays have dispersed the development of tunnel erosion depends on whether the soil matrix has sufficient permeability to enable dispersed soil material to move downslope through soil cracks and pores. This movement of dispersed clays leaves behind a small cavity. Further rainfall events, entrain more dispersed soil material, resulting in both the headward and tailward expansion of the cavity (Zhu 2003, Vacher *et al.* 2004, Laffan and Cutler 1977). Eventually cavities link-up to form a continuous tunnel system in which water flowing at the tunnel base, further scours the sidewalls resulting in slumping and tunnel enlargement (Figure 6) (Laffan and Cutler 1977, Zhu 2003). Eventually undermining reaches an extent where complete roof collapse occurs and either gully erosion forms (Figure 24) (Laffan and Cutler 1977), or the topsoil collapses back over the tunnel to form a stable depression (Figure 8).

Figure 6. Sidewall collapse due to mechanical scouring and undercutting sidewalls. Dolerite derived soils, Dunalley.

Tunnel erosion tends to be a sporadic phenomenon (Pickard 1999). Tunnel eroded areas may appear to be stable for periods up to a decade or more before a single runoff event re-initiates the erosion process (Zhu 2003). There may also be a significant time-lag between disturbance and the first observation of tunnelling. At one site in Kingborough, tunnel development only became apparent 10-15 years after the site was disturbed presumably as a result of dwelling construction. At a property on Bruny Island, a single summer storm in 2003 increased the section of a hillslope affected by tunnel erosion by around 30%. Observation indicates that tunnel initiation tends to occur late in summer when vegetation has died off and soils are desiccated and cracked (Floyd 1974, Vacher *et al.* 2004). Sudden downpours generate large amounts of surface runoff which enter the subsoil directly through soil cracks (Figure 7), dispersing sodic soil horizons and initiating the tunnel erosion process. Although greater rainfall generally falls over winter, tunnel initiation is uncommon during the winter months as clays tend to have swelled, sealing surface cracks and reducing the presence of void spaces within the soil (Floyd 1974).

Figure 7. Surface water entering an existing tunnel system, increasing the mechanical erosion and scoring.

Figure 8. Collapse of tunnel roof, following loss of dispersive soil horizon leading to formation of a stable depression, Cygnet.

3.0 IDENTIFYING DISPERSIVE SOILS

IDENTIFICATION OF DISPERSIVE SOILS

» Dispersive soils can be identified by dribble patterns and pitting.

» Early stages of tunnel erosion can be identified by the development of spew holes.

» Simple field tests can be used to identify the presence of dispersive soils.

» For engineering works or infrastructure development, a combination of analytical and physical tests should be used. Consult an appropriately qualified and experienced soil specialist or civil engineer.

3.1 FIELD TECHNIQUES

Dispersive soils may be readily identified by distinctive dribble patterns that form following exposure to rain or low electrolyte runoff. The presence of the distinctive 'dribble' patterns or 'worm channels' is considered to be a reliable indicator of moderately to highly dispersive soils (Figure 9) and is nearly always observed on the sidewalls of tunnel erosion cavities. Where topsoil has been removed by erosion or excavation, pitting and pocketing can occur in subsoils exposed to rainfall (Figure 10).

Figure 9. (a) Example of dribble pattern on an exposed subsoil, the photograph was taken from within an actively eroding tunnel system. (b) Dribble patterns on sodic soil ped.

Figure 10. 'Pitting & pocketing', resulting from topsoil removal, surface water has dissolved through the soil surface. Soils derived from Triassic Sandstone.

Figure 11. 'Sediment fans or 'spew holes' are often the first sign of tunnel erosion (a) Honeywood, (b). Woodbridge (c) Campania (d) Dunalley.

Early signs of tunnel erosion include the presence of sediment fans or 'spew holes' which result from the ejection of fine sediments and dispersed clays from the downslope end of a tunnel erosion system (Figure 11). It is however important to note that by the time a spew hole has developed, considerable sub-surface erosion may have already occurred.

3.2 SIMPLE FIELD TEST FOR IDENTIFYING DISPERSIVE SOILS

Field testing for dispersive soils can be conducted by observing the behaviour of air dried aggregates in distilled water or rainwater. This analysis is a simplification of the Emerson crumb test (Emerson 2002).

1) Collect soil aggregates (1-2 cm diameter) from each layer in the soil profile.
2) If moist, dry the aggregates in the sun for a few hours until air-dried.
3) Place the aggregates in a shallow glass jar or dish of distilled water or rain water. It may help to place the jar on black card or a dark surface (distilled water can be purchased at most supermarkets).
4) Leave the aggregates in water without shaking or disturbing them for 2 hours.
5) Observe and record if you can see a milky ring around the aggregates. Don't worry if the soil collapses or bubbles (Figure 12).

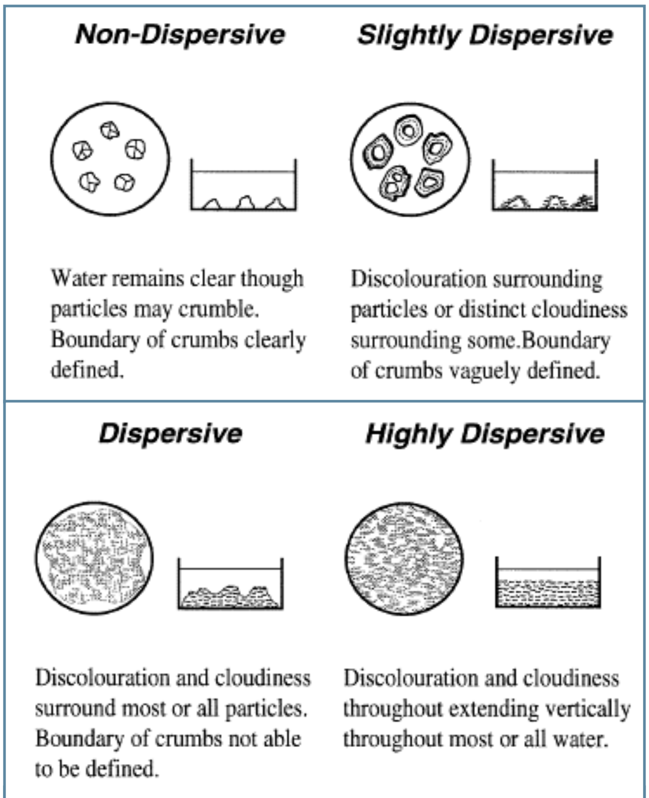

Figure 12. Field test for aggregate dispersion (Sorensen 1995).

Caution: Aggregates may not disperse when they should if they haven't been sufficiently dried. While the presence of a milky halo indicates the presence of dispersion, the absence of a milky halo does not necessarily mean that soil will not disperse. Some soils only disperse after they have been disturbed or remoulded. Further testing using an approved Australian Standard technique may be required.

3.3 LABORATORY TECHNIQUES FOR IDENTIFYING DISPERSIVE SOILS

Although a number of tests have been used to identify dispersive soils, no single test has been developed that can reliably identify all dispersive soils under all conditions (Bell and Maud 1994, Bell and Walker 2000). For civil engineering works or infrastructure development, it's suggested that a range of chemical and physical tests be employed rather than relying on interpretation of a single analysis (McDonald *et al.* 1981, Bell and Maud 1994, Bell and Walker 2000). McDonald *et al.* (1981) note that "there is urgent need for an agreed standard test or tests to identify dispersive soil. In the meanwhile, engineers should use a large number of inexpensive tests for screening, and confirm these as needed by more elaborate tests, adopting the most conservative evaluation." A review of analytical procedures for identifying dispersive behaviour in soils is presented by Bell and Maud (1994) and Bell and Walker (2000). It should also be noted that identification of soil dispersion does not necessarily imply that tunnel erosion will occur, as other factors such as water chemistry, site hydrology and soil porosity also influence the development of tunnel erosion.

CHEMICAL TESTS.

Chemical analyses such as ESP and SAR attempt to relate the relative abundance of exchangeable cations to aggregate stability and dispersion. Relationships between soil dispersion and chemical properties such as Exchangeable Sodium Percent (ESP), Cation Exchange Capacity (CEC), Sodium Absorption Ratio (SAR), and Electrical Conductivity (EC) have been developed for a limited range of soils (Elgers, 1985, Sherard *et al.* 1976, Gerber and Harmse 1987, Rengasamy *et al.* 1984). Use of chemical techniques for the prediction of soil dispersion have not been established for most Tasmanian soils. It should be noted that threshold levels for dispersion are arbitrarily defined (Sumner 1993) and that dispersion can occur in soils with ESP below 6 or SAR below 3 (further details and discussion of test procedures are provided in Appendix I).

PHYSICAL TESTS

The physical tests of soil dispersion such as the pinhole test and the Emerson crumb test rely on observation and ranking of soil dispersion in distilled water and / or dispersant. The performance of a range of analytical procedures for the prediction of soil dispersion has been conducted by a number of authors including; Bell and Maud (1994), Bell and Walker (2000), Sherard *et al.* (1976), Moore *et al.* (1985) and Elges (1985). Review of these studies generally indicate that the Emerson crumb test (Emerson 2002) and the pinhole test to be the most reliable tests for predicting dispersive behaviour of soils, while the pinhole test (AS 1289.3.8.3 – 1997) was rated the most reliable single test for identification of soil dispersion associated with earth works such as dams or embankments, (further details and discussion of test procedures is provided in Appendix I).

4.0 APPROACHES FOR MINIMISING EROSION RISK IN DISPERSIVE SOILS

MINIMISE RISK OF TUNNEL EROSION BY;

- Identifying and avoiding disturbance to areas with dispersive subsoils.
- Minimising excavation of dispersive soils.
- Not allowing water to pond on the soil surface, or exposed subsoils.
- Keeping sodic sub-soils buried under topsoil.
- Maintaining vegetation cover.

UNDERSTAND THAT;

- The presence and severity of dispersive soils may vary enormously over short distances.
- Past efforts to control field tunnel erosion have often failed.

STRATEGIES FOR REDUCING THE RISK OF TUNNEL DEVELOPMENT IN PERI-URBAN AREAS INCLUDE;

- Soil testing and avoidance.
- Precise compaction.
- Chemical amelioration.
- Sand filters and sand blocks.
- Topsoiling and revegetation.

4.1 MANAGEMENT OPTIONS FOR TUNNEL EROSION

Past efforts to repair tunnel erosion in agricultural landscapes have relied on mechanical destruction of the tunnel system by deep ripping, contour furrowing, and contour ripping. Unfortunately many of these techniques either failed or resulted in tunnel re-emergence in an adjacent areas (Floyd 1974, Boucher 1995). The use of these 'agricultural' techniques is inappropriate in peri-urban areas where tunnel repair requires a low incidence of re-failure due to the potential for damage to infrastructure. Experience with the construction of earth dams using dispersive clays, demonstrates that repair and prevention of tunnel erosion in urban and peri-urban environments is best achieved using a combination of,

» Identification and avoidance of dispersive soils.

» Precise re-compaction.

» Chemical amelioration.

» Sand blocks and barriers.

» Topsoil, burial and revegetation.

4.2 IDENTIFICATION AND AVOIDANCE OF DISPERSIVE SOILS

The risk of tunnel erosion resulting from construction activities on dispersive soils can often be reduced or eliminated by identifying and avoiding areas containing dispersive soils. The presence and severity of dispersive soils can vary enormously over short distances (Figure 13). In many instances, large scale (ie 10 x 10 or 20 x 20 meter grid) soil survey and screening of soils for dispersion, (using the Emerson crumb test - section 3, Appendix I) can be used to site dwellings and infrastructure away from dispersive soils. Advice should be sought from a suitably qualified and experienced engineer or soil professional.

Figure 13. The severity (or sodium content) and depth of dispersive subsoils can vary considerably over short distances. (a). At this site highly dispersive subsoils exist meters away from (b) non-dispersive soils.

4.3 COMPACTION

Ritchie (1965) demonstrated that the degree of compaction within the dam wall was the single most important factor in reducing dam failure from piping (tunnel erosion). A high degree of compaction reduces soil permeability, restricting the movement of water and dispersed clay through the soil matrix, which decreases the severity of dispersion and restricts tunnel development (Vacher *et al.* 2004). However, dispersive soils can be difficult to compact as they lose strength rapidly at or above optimum moisture content, and thus may require greater compactive force than other soils (McDonald *et al.* 1981). Bell & Bryun (1997) and Bell and Maud (1994) suggest that dispersive clays must be compacted at a moisture content 1.5 -2% above the optimum moisture content in order to achieve suficent density to prevent piping (Elges 1985).

Construction of structures such as earth dams and footings for buildings with dispersive soils require geotechnical assessment and advice from a qualified and experienced engineer, in order to determine compaction measures such as the optimal moisture content, number of passes, and maximum thickness of compacted layers.

Normal earth moving machinery including bull-dozers, excavators and graders do not provide sufficient compactive force to reduce void spaces or achieve adequate compaction in dispersive soils. A sheepsfoot roller of appropriate weight is usually required to compact dispersive soils. By comparison a D6 dozer applies only 0.6 kg/cm^2 pressure compared to 9.3 kg/cm^2 for a sheepsfoot roller (Sorensen 1995).

4.4 CHEMICAL AMELIORATION

Initiation of tunnel erosion is predominantly a chemical process, so it makes sense to use chemical amelioration strategies when attempting to prevent or repair tunnel erosion in dispersive soils. Despite the widespread use of gypsum and lime to treat sodic soils in agriculture, the use of gypsum and lime to treat tunnel affected areas has been relatively rare (Boucher 1990).

Hydrated lime (calcium hydroxide) has been widely used to prevent piping in earth dams. Rates of application have varied depending on soils and degree of compaction used in construction. Laboratory testing usually indicates that only around 0.5 –1.0% hydrated lime is required to prevent dispersion, however difficulties with application and mixing necessitate higher rates of application (Moore *et al.* 1985). Moore *et al.* (1985) cite examples of the use of hydrated lime to control piping in earth dams at rates between 0.35% (N.S.W. Australia) and 4% (New Mexico). Elgers (1985), and McElroy (1987) recommend no less than 2% hydrated lime (by weight of the total soil material) to prevent dispersion within dam embankments, while Bell and Maud (1994) suggest that 3% - 4% by mass of hydrated lime should be added to a depth of 0.3m on the upper face of embankments. In alkaline (pH >7.0) soils (most sodic subsoils in Tasmania are neutral or alkaline) the effectiveness of hydrated lime is reduced by the formation of insoluble calcium carbonate (Moore *et al.* 1985), such that gypsum is preferred to hydrated lime. It is important to note that agricultural lime (calcium carbonate) is not a suitable substitute for hydrated lime due to its low solubility (McElroy 1987). Also note that excessive applications of lime may raise soil pH above levels required to sustain vigorous plant growth.

Gypsum (calcium sulphate) is more effective than lime for the treatment of dispersive soils as it increases the electrolyte concentration in the soil solution as well as displacing sodium with calcium within the clay structure (Raine and Loch 2003). Gypsum is less commonly used than hydrated lime in dam construction and other works due to its lower solubility, and higher cost. Elges (1985) recommends that in construction, a minimum of 2% by mass of gypsum be used. Bell and Maud (1994) present a means of calculating the amount of gypsum required to displace excess sodium and bring ESP values within desired limits (normally < 5). Be aware that application of excessive amounts of gypsum may cause soil salinity to temporarily rise beyond the desired level for plant growth.

NOTE:

- Use of gypsum in Tasmania is covered under the Fertiliser Act 1993, which has established the allowable limit for cadmium and lead at 10 mg/kg and 5 mg/kg for mercury.
- Gypsum is usually imported into Tasmania from Victoria or South Australia, which have different standards for allowable heavy metal content.
- Purchasers of gypsum should check with suppliers to ensure that gypsum imported into Tasmania is compliant with current regulations.

Alum (aluminium sulphate) has been effectively used to prevent dam failure and protect embankments from erosion. Application rates are not well established. Limited data suggests mixtures of 0.6 –1.0% (25% solution of aluminium sulphate) (Bell and Bruyn 1997, McElroy 1987) to 1.5% (Ouhadi, and Goodarzi 2006) of the total dry weight of soil may be appropriate. Alum is however highly acidic (pH 4-5), and thus alum treated soils will need to be capped with topsoil in order to establish vegetation (Ryker 1987). Soil testing is required to establish appropriate application rates for Tasmanian soils.

Long chain polyacrylamides have been shown to increase aggregate stability, reduce dispersion and maintain infiltration rates in dispersive soils (Levy *et al*. 1992, Raine and Loch 2003). However the effect is highly variable between various polyacrylamide products and the chemical and physical properties of the soil. The benefit of polyacrylamides is generally short due to their rapid degradation (Raine and Loch 2003). Further advice and laboratory testing should be conducted before using polyacrylamides to protect earth dams from piping failure.

Note that appropriate application rates for gypsum, hydrated lime, alum and polyacrylamides have not been established for dispersive soils in Tasmania. Extensive laboratory assessment of materials used for the construction of dams or embankments is required before locally relevant 'rules of thumb' can be established for the use of these products.

4.5 SAND BLOCKS AND SAND BARRIERS

Sand filters were first developed to prevent piping in earth dams. Sand filters prevent dam failure by trapping entrained sand and silt, blocking the exit of the tunnel and preventing further tunnel development (Sherard *et al.* 1977). Following the work of Sherard *et al.* (1977), Richley (1992 and 2000) developed the use of sand blocks to prevent tunnel erosion during installation of an optical fibre cable in highly dispersive soils near Campania, Tasmania. The sand blocks work slightly differently to the sand filters in that they allow the free water to rise to the surface through the sand. The use of sand blocks has recently been modified by Hardie *et al.*, (2007) to prevent re-initiation of tunnel erosion along an optical fibre cable near Dunalley. Modifications to the original technique developed by Richley (1992 and 2000) include (Figure 14 &15);

- Upslope curved extremities to prevent the structure from being by-passed.
- Geotextile on the downslope wall to prevent collapse or removal of sand following settlement or erosion.
- Application of gypsum (around 5% by weight) to ensure infiltrating water contains sufficiently electrolyte to prevent further dispersion.
- Earth mound upslope of the structure to prevent run-on entering the sand blocks.

Figure 15. (a) Installation of sandblock perpendicular to a service trench. Note securing of geotextile to the optical fibre cable to prevent water flowing past the sand block. (b) Sandblock before final topsoiling.

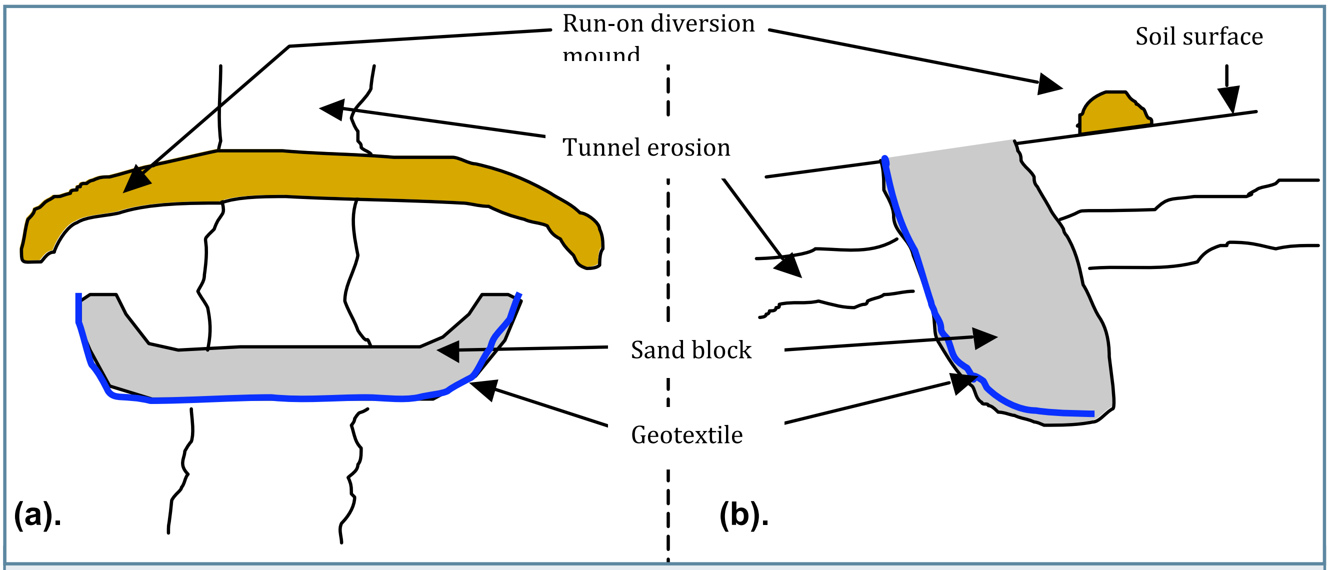

Figure 14. Modified sand block design. (a) plan view, (b) cross section view. The depth of the sand block is determined by the depth of dispersive soils or tunnel erosion. The span length of the structure is determined by the width of the tunnelling.

4.6 USE OF TOPSOIL / BURIAL AND REVEGETATION

Topsoil or burial of exposed dispersive soils reduces the likelihood of subsoil dispersion and initiation of tunnel erosion by;

- Providing a source of salt to increase the electrolyte content of infiltration water.
- Preventing desiccation and subsoil cracking.
- Promoting even infiltration.
- Providing a protective cover from raindrop impact.
- Providing a suitable medium for revegetation.

Topsoil minimises the interaction between water and dispersive clays by providing both a physical and chemical barrier. Topsoil also reduces soil desiccation and development of surface cracks (Sorensen 1995). It is suggested that exposed dispersive subsoils be covered with at least 150mm of non dispersive topsoil and sown with an appropriate mix of grass species. In some cases it will be necessary to protect the topsoil from erosion with 'jute' cloth or similar product.

The suitability of planting trees in tunnel affected areas is influenced by the amount of annual rainfall and frequency of soil cracking resulting from desiccation. Boucher (1995) recommends the preferred option for revegetation of reclaimed tunnel erosion is a widely spaced tree cover in association with a combination of perennial and annual pastures, rather than a dense stand of trees or pasture alone. Experience in Tasmania suggests that in low rainfall areas, or areas in which existing trees or shrubs cause soil drying and cracking, the preferred option for revegetating tunnel affected land is a dense healthy pasture. In high rainfall areas, dense plantings of trees have been successfully used to repair or stabilise tunnel erosion for example Colclough (1973) successfully used Pinus radiata to stabilise tunnel-gully affected land in a moderate rainfall area near Tea Tree, Tasmania.

5.0 ACTIVITIES THAT INCREASE THE RISK OF EROSION ON DISPERSIVE SOILS

ACTIVITIES THAT INCREASE RISK OF INITIATING TUNNEL EROSION, INCLUDE;

- Removal of topsoil.
- Soil excavation or expose of subsoils to rainfall.
- Supply of services via trenches.
- Construction of roads and culverts in dispersive subsoils.
- Installation of sewage and grey water disposal systems in dispersive subsoils.
- Dam construction from dispersive soils.

OPTIONS FOR REDUCING THE RISK OF TUNNEL EROSION DURING CONSTRUCTION AND DEVELOPMENT WORKS ON DISPERSIVE SOILS INCLUDE,

- Where possible do not remove or disturb topsoil or vegetation.
- Ensure that dispersive subsoils are covered with an adequate layer of topsoil.
- Avoid construction techniques that result in exposure of dispersive subsoils.
- Use alternatives to 'cut and fill' construction such as pier and post foundations.
- Where possible avoid the use of trenches for the supply of services ie water & power.
- If trenches must be used, ensure that repacked spoil is properly compacted, treated with gypsum and topsoiled.
- Consider alternative trenching techniques that do not expose dispersive subsoils.
- Ensure runoff from hard areas is not discharged into areas with dispersive soils.
- If necessary create safe areas for discharge of runoff.
- If possible do not excavate culverts and drains in dispersive soils.
- Consider carting non-sodic soil to create appropriate road surfaces and drains without the need for excavation.
- Ensure that culverts and drains excavated into dispersive subsoils are capped with non-dispersive clays mixed with gypsum, topsoiled and vegetated.
- Avoid use of septic trench waste disposal systems; consult your local council about the use of alternative above ground treatment systems.
- Where possible do not construct dams with dispersive soils, or in areas containing dispersive soils.
- If dams are to be constructed from dispersive clays, ensure you consult an experienced, qualified civil engineer to conduct soil tests before commencing construction.
- Construction of dams from dispersive soils is usually possible, using one or a combination of: precise compaction, chemical amelioration, capping with non-dispersive clays, sand filters and adequate topsoiling.

With all forms of construction on dispersive soils, ensure you obtain advice and support from a suitably experienced and qualified engineer or soil professional before commencing work.

5.1 ACTIVITIES THAT PROMOTE TUNNEL EROSION

In almost all cases tunnel erosion results from some form of disturbance resulting in rainwater or water with very low salt content coming into contact with dispersible subsoil. Changes to hydrology, such as concentration of flow in culverts, runoff from hardened areas and ponding of rainfall all increase risks of tunnel erosion. Typical activities that increase the risk of exposing dispersive subsoils to rainfall include;

- Removal of topsoil.
- Soil excavations.
- Trenches and supply of services.
- Roads and culverts.
- Sewage and grey water disposal.
- Dam construction.

5.2 REMOVAL OF TOPSOIL.

Topsoil provides both a physical and chemical barrier to infiltrating water (see section 4.6). Removal or stockpiling of topsoil for even relatively short periods can result in the initiation of tunnel erosion (Figure 16). If dispersive subsoils are exposed during construction, ensure they are covered with topsoil or dusted with gypsum and that rainfall does not have the opportunity to collect and pond.

Figure 16. Initiation of tunnel erosion caused by scalping or removing topsoil. Note that even a very thin layer of topsoil was able to prevent widespread tunnel erosion

5.3 CUT AND FILL

The use of 'cut and fill' excavation techniques (road cuttings, housing pads etc.) should be avoided in areas containing dispersive soils. Excavation can lead to the development of 'outlet initiated' tunnel erosion resulting from the removal of overburden (Figures 17 and 28) (Crouch *et al.* 1986, Vacher *et al.* 2004). While this form of tunnel erosion is rarely as extensive or deep as other forms of tunnelling, outlet initiated tunnelling can be difficult to repair and results in the deposition of sand and 'spewey' clays around the back of dwellings or in culverts.

Figure 17. Extensive 'outlet initiated' tunnel and rill erosion caused by excavating a cut and fill pad for a large building in a dispersive soil. Triassic sandstone parent material.

Although less commonly observed than the outlet initiated tunnelling, development of tunnel erosion in footings constructed from dispersive soils can occur as a result of rainfall ponding on dispersive fill. Note that in Figure 18 tunnelling has developed on a flat area without the need for a slope to generate water movement.

Figure 18. (Same site as Figure 17) Tunnel erosion in footings intended for a large building. Erosion resulted from ponding of rainwater on highly dispersive fill. The fill contains a number of narrow slots (up to 1.2 meters deep) caused by surface water 'dissolving' through the footing.

Seek experienced and qualified geotechnical advice from a suitably qualified civil engineer or appropriate soil specialist if a structural fill or footing is to be constructed from or into dispersive soils.

In areas with dispersive soils, pier or post style construction (Figure 19) is a low risk option for the construction of footings. Footings will need be excavated beneath any sodic layers and / or pinned to the basement rock. Post holes should be completely filled and capped with concrete above the soil surface, rather than backfilled with spoil. Runoff and surface water must be safely directed away from the building, or prevented from flowing near the foundations.

Figure 19. Pier or post style construction has considerably lower risk of initiating tunnel erosion than cut and fill techniques.

5.4 TRENCHES AND SUPPLY OF SERVICES

Services such as electricity, telecommunications and water are usually supplied to dwellings via trenches from mains outside the property. In areas with dispersive subsoils, supply of services by trenches increases the risk of initiating tunnel erosion (Figure 21b) (Richley 1995 & 2000, Hardie *et al.* 2007). Unfortunately most service providers are unfamiliar with the issues associated with dispersive soils, and may need assistance to understand why alternative supply options may need to be considered. Electricity and telecommunications can be supplied by private power poles resulting in minimal soil disturbance, provided that the poles are installed using augurs rather than excavated trenches (Figure 21a) and that the hole is completely filled with concrete above the soil surface or repacked with a mixture of gypsum and soil, with a high level of compaction. Spoil should be removed from the site.

EMERGING TECHNIQUE: HYDROLOGICAL BARRIER

This technique for diverting surface and subsurface water away from footings has been proposed as an alternative, or an addition to pier or post foundations. The hydrological barrier technique involves construction of a sand and gypsum filled trench to the depth of the foundations around the upslope area of the dwelling (Figure 20). The sand – gypsum mixture acts to trap the dispersed silts pugging up the developing tunnel while allowing the water to come into contact with the gypsum and rise through the sand and away from the footings. An earth mound immediately above the sand filled trench acts to prevent surface runoff entering the trench. The hydrological barrier can be installed either during construction or fitted to existing dwellings after construction. While the hydrological barrier technique has only been trialled once in Tasmania (Ducket pers. comm.) the design principles result from successful use of sand blocks (Figures 14 & 15) for the prevention of tunnel erosion resulting from the installation of optical fibre cables in dispersive soils (Richley 1995 & 2000, Hardie *et al.*, 2007).

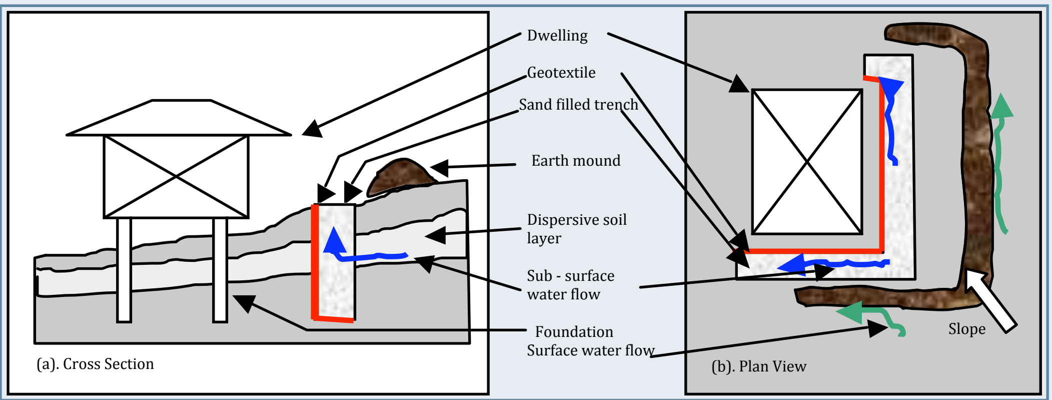

Figure 20. Hydrological barrier to isolate foundations from surface and groundwater (Duckett pers. comm.), (a) cross section view, (b) plan view.

Alternatives to the use of trenches for the supply of potable water and other services will need to be approved by your local council. Examples include laying cable or pipe in the thin topsoil then carting more topsoil to the site to ensure adequate burial depth (Figure 22c). Alternatively the cable may need to be laid in hard conduit on the soil surface and buried with non-dispersive soil (Figure 22a). Any earthworks on the site must ensure that rainwater is not able to collect and pond on the soil surface, such that additional soil may be required to ensue that any buried cable or pipe is level with the land surface (Figure 22b). The remaining mound can be landscaped into the surrounding garden provided that trees and large shrubs are not planted in such a way as to prevent future access to the pipe.

Figure 21 (a) Tunnel erosion initiated by installation of an optical fibre cable into a dispersive soil. (b) Subsidence and early stages of tunnelling resulting from inappropriate installation of power pole in a backfilled trench.

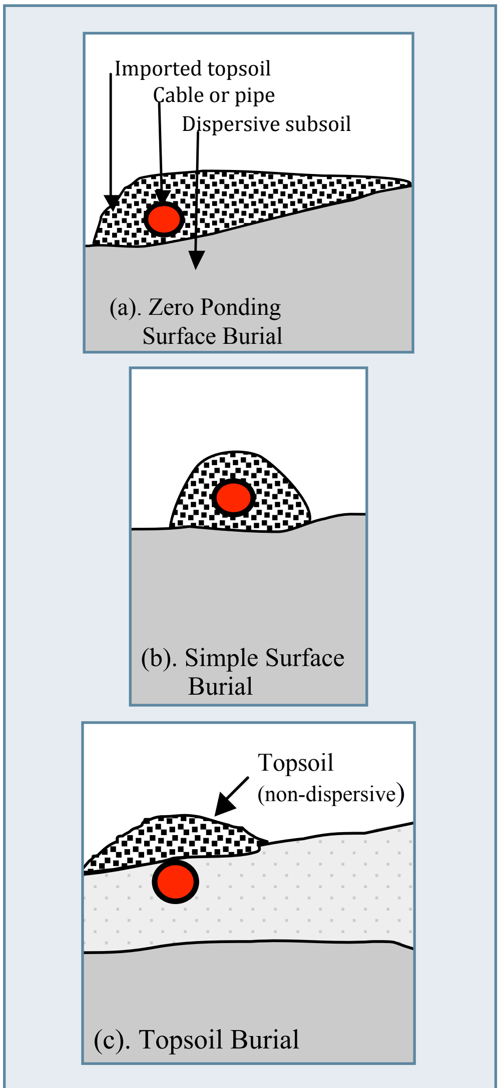

Figure 22. Cable and pipe installation techniques. (a) Good technique, surface burial of pipe or cable ensuring that ponding cannot collect on or behind the mound. (b) Average technique, simple surface burial, however ponding can occur behind the mound. (c) Good technique, where topsoil depth allows partial burial.

Trenches may be used to supply services such as water and electricity, however in dispersive soils, the increased porosity of repacked spoil within the trench can lead to tunnel erosion and damage to pipes and cables (Figures 6 & 21b). If a trench must be used, then use of chemical amelioration, sand blocks and precise compaction can lower the risk of tunnel formation. Richley (1992) used sand blocks to prevent development of tunnel erosion along an optical fibre cable installed in highly dispersive soil near Campania, and Hardie *et al.* (2007) used a combination of chemical amelioration, compaction and sand blocks to prevent re-initiation of tunnel erosion following repair of a 380m long tunnel erosion system near Dunalley.

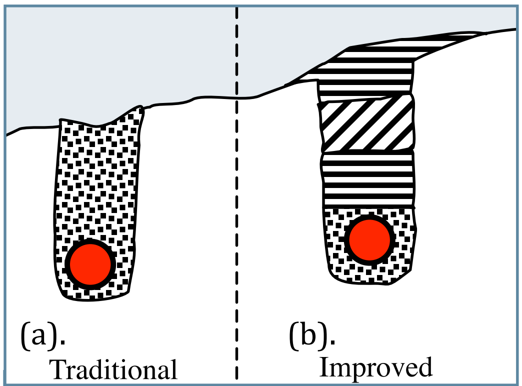

Figure 23. Improved trench design. (a). Traditional Trench. Note surface sinks allowing water to pond above trench. (b) Improved trench with individually compacted clay layers. The surface is finished above the ground surface to prevent ponding on top of the trench.

5.5 STORM WATER AND RUNOFF

Storm water and runoff from hard surfaces such as driveways and courtyards, need to be managed to prevent initiation of tunnel erosion (Trangmar 2003, Vacher *et al.* 2004). Stormwater and runoff should not be allowed to collect or pond on dispersive soils. Runoff should be directed away from susceptible areas (exposed dispersive soils) through the use of pipes or diversion mounds created from imported non-dispersive clays rather than trenches or culverts which risk excavation and exposure of dispersive subsoils (Figure 24). Captured runoff should be dissipated and spread over as wide an area as possible, not concentrated in drainage lines. Where possible dispose of captured water in 'safe' areas such as;

» Garden beds mixed with gypsum.
» Existing well vegetated areas with ample topsoil.
» Stony elevated areas (Trangmar 2003).

If no other options exist, then a garden bed with ample topsoil and gypsum (around 2 -5 % of total soil volume) may need to be created away from dwellings or infrastructure. Wherever possible use rainwater tanks to capture runoff from roofs and buildings, but note that overflows will also need to be piped to 'safe' areas.

Figure 24. Tunnel erosion resulting from construction of a stormwater culvert in dispersive clay derived from Triassic sandstone, Brighton.

5.6 ROADS AND CULVERTS

Construction of roads or driveways on dispersive soils is difficult due to their low bearing capacity when wet (Figure 25). Concentrating water in roadside culverts and drains which have been excavated into dispersive soils often leads to erosion and collapse of the road batter adjacent embankments (Figures 26-28). Soil surveys may assist landholders / councils to locate roads in areas containing non-dispersive soils, however in most cases managing runoff without excavating culverts is the best means of reducing the erosion risk.

Figure 25. Road surface breaking up due to construction on dispersive clays. This section of road is repaired 2-3 times a year.

Figure 26. Undercutting and collapse of roadside batter due to construction of a table drain in dispersive clay. Note the failure of the blue rock rap to prevent further erosion.

Figure 27. Table drain constructed in dispersive subsoil. The concentration of runoff in the culvert is greatly adding to the erosion problem, resulting in slumping and undercutting of the road and the adjacent batter slope. This photo was taken 18 months after the driveway was constructed.

Figure 28. Rill and tunnel erosion caused by excavation of sodic soils for road construction. Dunalley.

Table drains should not be constructed in dispersive soils (Figure 26 & 27). If topsoil depth is insufficient to allow table drains to be constructed without exposing dispersive soils, then alternative forms of road construction and drainage need to be considered. Road design needs to ensure runoff is spread out and dissipated over wide, well vegetated areas. On steep slopes, minor roads are best constructed straight up and down the slope with speed hump like barriers across the road surface to shed water to the sides (Figure 29 - Duckett *pers. comm.*). Consideration should be given to spreading topsoil, applying gypsum and re-vegetating either side of the roadway to ensure runoff doesn't initiate further tunnelling.

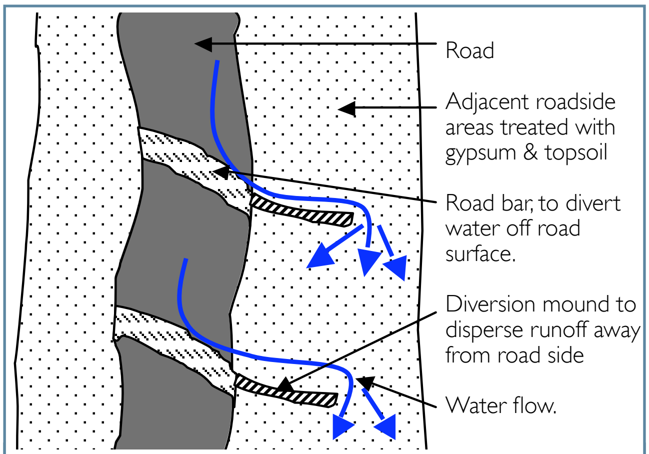

Figure 29. Alternative road design using road bars and diversion mounds to shed water into stable areas.

Where it is necessary to excavate drains and culverts in dispersive soils, it is suggested that the exposed subsoil is treated with gypsum or hydrated lime then capped with a thick layer (i.e. 200-300mm) of non-dispersive clay (test for dispersion using procedure in section 3) preferably also mixed with either gypsum or hydrated lime. The clay capping should be covered with topsoil and revegetated if appropriate. Alternatives to the use of clay capping include the use of bitumen spraying and hydro-mulching, however few details of these techniques are available.

5.7 SEWAGE AND GREY WATER

Experience from the Brighton municipality has demonstrated that septic tank systems do not perform adequately in dispersive soils. Installation of septic systems in dispersive soils have resulted in the initiation of tunnel erosion resulting in health risks associated with uncontrolled discharge of effluent (Parkinson pers. comm.).

Brighton council have tested five different domestic wastewater treatment and disposal systems for use in dispersive or shallow soils (Parkinson & Palmer unpublished). Three systems were found to be viable: Recirculating Sand Filter (RSF), Pulse Dosed Aerobic Sand Filter (PDASF) and Effluent Landscape Mound (ELM), table 1).

Of the three systems, the Pulse Dosed Aerobic Sand Filter (PDASF) produced the highest level of treatment however at the time of the study the Effluent Landscape Mound (ELM) was the only system to be accredited by Australian Standards (AS1547, 2000). Other systems with similar or better performance have been developed since the original study. Check with your local council or a suitably qualified and experienced consultant to determine which operating systems meet current standards and would be best suited to your soils and level of occupancy.

Figure 30. Ozzi Kleen single tank (Aerated Wastewater Treatment System) for treatment and disposal of sewage and grey water. Raised – mulched area in foreground is being used for effluent disposal from the house in background.

Table 1: Alternative sewage and grey water treatment systems for dispersive or shallow soils. *(Parkinson & Palmer unpublished).*

	Sand Bed Size (meters)	Tank Requirement	Suitability for Above Ground Spray	Final Quality (cfu / 100mL)	Australian Standard
Recirculating Sand Filter	2 x 6 x1	2.4 meter diameter, and filter & effluent pump wells.	Yes	0-10	No
Pulse Dosed Aerobic Sand Filter	10 x 4 x1 and rock filter 12 x 1.5 m x 0.4	2 x 3000L and filter & effluent pump wells	Yes	0-10	No
Effluent Landscape Mound	18 x 6.5 x 1	4500L, Dosing And effluent pump wells.	Required additional disinfection or subsoil application.	<50	Yes AS 1547, 2000

Alternatively composting toilets provide a no-water, zero tunnelling risk option for the treatment of sewage in areas with dispersive soils (Figure 31). Composting toilets offer a practical low risk and environmentally sustainable alternative to standard flushing toilets.

Figure 31. Example of a composting toilet system. (Source www.nature-loo.com.au)

5.8 DAM CONSTRUCTION

Dispersive soils are inherently unsuited to dam construction. A survey by Foster *et al.* (2000) found that 48% of dam failures resulted from piping (internal tunnelling) and that 42% of these failures occurred on first filling. Dams constructed from dispersive clays are always 'muddy' and are rarely suitable for swimming. Small farm and amenity dams are particularly prone to tunnel failure as they are frequently built without regulation, soil testing, or engineering advice. Serious consideration should be given to whether constructing a dam is necessary, and the potential consequences of dam failure before building a dam in an area containing dispersive soils.

Tunnel erosion or piping in dam walls results from fresh water dispersing sodic clays within the embankment. The dispersed clays flow into void spaces created by insufficient compaction during construction. Movement of dispersed clays creates increasingly larger cavities until a continuous tunnel or pipe is formed between the inner and outer wall, at which point dam failure occurs (Figures 33-35). The likelihood of failure of dams built with dispersive soils depends on a number of factors (Vacher *et al*. 2004) including,

- The rate of first filling.
- The degree of compaction during construction.
- The dispersibility of materials used to construct the dam.
- The electrolyte content of the soil solution.
- The electrolyte concentration of the stored water.

Figure 32. The dam in the foreground has been constructed from dispersive clays. Note the rill erosion and cloudy brown colour of water in foreground, compared to the blue colour of the dam constructed from non-dispersive soils in the background.

Figure 33. Typical small dam failure. Note piping through the side wall of the dam. This dam was constructed using dispersive clays derived from Triassic sandstone.

Figure 34. Piping failure of a dam constructed from soils derived from Permian mudstone, Penna area. This dam is known to have failed on first filling. The image was taken from the dam floor, looking at the inside of the dam wall.

Figure 35. Failure of Blackman Creek dam (source: Davies Brothers). In 2005 the Blackman creek dam failed, resulting in the evacuation of Tunbridge. Doyle and Cumming (unpublished 2005) indicate the cause of the failure to be variability in the compaction of a slightly to a moderately dispersive soil layer, combined with rapid filling of the dam with low electrolyte water.

The risk of tunnel or piping failure in small earth dams can be minimised by a combination of control measures including;

- **i)** Adequate compaction
- **ii)** Chemical ameliorants e.g. gypsum, hydrated lime etc.
- **iii)** Sand filters.
- **iv)** Construction with non-dispersive clay.
- **v)** Topsoiling.

Construction of earth dams with dispersive soils is usually possible if adequate compaction can be achieved (Bell and Maud 1994). Ritchie (1965) demonstrated that the degree of compaction within the dam wall is the single most important factor in reducing dam failure. The importance of other factors such as batter angle, rate of filling or moisture content during construction were all secondary to that of compaction. Dispersive soils can be difficult to compact as they lose strength rapidly at or above optimum moisture content, and thus may require greater compactive force if moisture contents are just dry of optimum (McDonald *et al.* 1981). A sheeps foot roller is required to adequately compact dispersive soils as normal earth moving machinery cannot provide enough compactive force. (Refer section 4.3).

Chemical ameliorants such as hydrated lime (calcium hydroxide), gypsum (calcium sulphate), alum (aluminium sulphate) and long chain polyacrylamides have been used to prevent dispersion and piping in earth dams. Hydrated lime is the most commonly applied product with the rate varying between 0.5 to 4.0 % by weight, depending on soil chemistry and level of dispersion (Moore *et al.* 1985, McElroy 1987, Elgers 1985, Bell and Maud (1994). Gypsum may also be used but its lower solubility and higher cost may limit its use. Gypsum is more effective than lime due to its higher electrolyte content which prevents dispersion as well as improves clay structure. Gypsum may also be added to the dam water to artificially increase the electrolyte (salt) concentration of the dam water, to minimise the risk of failure upon first filling (McDonald *et al.* 1981). (Refer section 4.4).

CASE STUDY: BEN BOYD DAM, NSW.

The Ben Boyd dam in New South Wales was protected from tunnel erosion or piping failure through a combination of chemical amelioration, precise compaction and increasing the electrolyte content of the inflowing waters.

The earth dam was successfully constructed with dispersive clays with ESP values as high as 20.7, (average 7.5) in an area known to contain very low electrolyte stream flow. Gypsum was applied to the dam structure at a rate of 1% by weight or 27 tonnes per hectare over the storage area. The gypsum was cultivated into the inner wall of the dam to a depth of 150cm and then compacted with a vibrating sheepsfoot roller. The infilling water was dosed with gypsum and alum to raise the electrolyte concentration from around 70 mg/l to 300-600 mg/l (McDonald *et al.* 1981).

Sand filters can effectively seal and safely control leaks in dispersive clays. While sand filters are unable to 'trap' dispersed clays, the sands and silts are effectively 'trapped' sealing the exit of the tunnel and preventing further tunnel development (Sherard *et al.* 1977). (Refer section 4.5).

Dams constructed with low to moderately dispersive clays can often be protected from piping by capping the upper dam wall with a thick layer of compacted non dispersive clay, usually mixed with either hydrated lime or gypsum. Topsoiling and re-establishment of vegetation minimises the interaction between water and dispersive clays by providing both physical and chemical barrier to infiltrating water. Topsoil also reduces soil desiccation and development of surface cracks. (Refer section 4.6).

6.0 REPAIR AND REHABILITATION OF TUNNEL EROSION

While the techniques outlined in this document represent the best available knowledge at the time of writing, it should be recognised that repair and rehabilitation works are prone to re-failure and that the techniques outlined below (and in the wider literature) have not been validated by replicated field trials or adequate long term monitoring. Differences between field sites, erosion processes and long term landuse of the reclaimed area may affect the success of repair works.

- » Repair of tunnel erosion is expensive, difficult and prone to re-failure.
- » Existing literature is focused on repair of field tunnel erosion in agricultural landscapes rather than urban or peri-urban areas.
- » A combination of chemical, physical and vegetative measures are required to repair tunnel erosion.
- » Repair of tunnel erosion in peri-urban areas should consider use of controlled compaction, chemical amelioration, sandblocks, and topsoiling.
- » Revegetate repaired areas with fast growing locally appropriate pasture species and trees in higher rainfall areas.
- » Seek professional assistance.

Repairing tunnel erosion is expensive, difficult and prone to re-failure. Every effort must be made to prevent the formation of tunnel erosion before intervention is required. Literature on the repair and rehabilitation of tunnel erosion is scarce and focused on agricultural landscapes rather than protection of infrastructure in urban environments. The history of tunnel erosion control and repair has been reviewed by Boucher (1990), and Ford *et al.* (1993). Boucher (1990) identified the need for a combination of mechanical, vegetative and chemical measures to control and repair tunnel erosion, however Boucher (1990) and Boucher (1995) also note that many past attempts to repair tunnel erosion have failed or been responsible for initiating further tunnelling.

In Tasmania, Colclough (1965, 1967, 1971, 1973 and 1978) pioneered early techniques for controlling tunnel erosion and Richley (1992 and 2000) demonstrated the use of sand blocks to prevent the development of tunnel erosion following installation of an optical fibre cable. Hardie *et al.*, (2007) detailed advances in repair and rehabilitation techniques resulting from experience gained with the rehabilitation of a 380 meter long tunnel erosion system in Dunalley, Tasmania.

It is strongly recommended that a suitably qualified soil professional, with first hand experience in dispersive soil management be consulted before embarking on any repair or rehabilitation works. The approach outlined below has been developed following, extensive review of literature, expert opinion from erosion consultants and first hand experience of repairing tunnel erosion.

GENERAL RECOMMENDATIONS FOR REPAIR OF TUNNEL EROSION IN PERI-URBAN AREAS.

1) Where possible cut off or divert surface water away from the tunnel system using diversion mounds rather than drains. Earthworks must be conducted without exposing dispersive subsoils. Experience has sown that identification of 'safe' areas is rare and usually dependant on there being a change in soil type or geology. If there is any doubt that a disposal area is 'safe' then works to divert flow from the head of the tunnel system should be abandoned.

2) Identify the true head of the tunnel system to determine the scale of intervention work required. This usually requires chasing tunnels with an excavator and use of coloured dye to trace water movement.

3) If tunnels are shallow and reappearance of tunnel erosion is not likely to impact on critical infrastructure, then deep ripping and cultivation techniques may be used to destroy the tunnel system (see Floyd 1974, Colclough 1965 & 1971).

4) If tunnels extend below the maximum depth of deep ripping, or if critical infrastructure is at risk from tunnel reappearance, then control and repair options will require a higher level of intervention to lower the risk of re-failure.

5) Tunnel systems will need to be dug out along their entire path using an excavator.

6) If soils have a low to moderate risk of dispersion (ESP 6 - 15), or if the consequences of tunnel reappearance is low, then the dispersive soils excavated from the trench can be treated with gypsum and repacked back into the excavated area.

7) If soils are highly dispersive (ESP> 15) or the risk of tunnel reappearance may cause damage to infrastructure, then non- dispersive clays will need to be carted to the site and repacked in the trench. Repacked soils should also be mixed with gypsum as an additional measure against future dispersion.

8) All material repacked into the trench needs to be compacted to at least 95% of proctor maximum. Compaction is best achieved using a sheepsfoot roller. Track rolling with an excavator or back hoe is not adequate. Alternative compaction techniques may be available.

9) The surface of the repacked material should be finished with a convex shape to ensure runoff is not able to pond on top of the reclaimed area. The upper surface of the repaired work should be treated with gypsum to act as an electrolyte source for water infiltrating into the repacked spoil.

10) Treated areas and exposed subsoils should be covered with topsoil and revegetated with fast growing, locally appropriate species such as cocksfoot, ryegrass, and clovers. Fertiliser may also need to be applied to ensure adequate establishment.

11) Bare areas above the tunnel head may need to be treated to minimise runoff through use of scarifying, topsoil, fertiliser and sowing locally appropriate pasture species.

12) Consideration should be given to applying gypsum over the whole area at a rate of approximately 1.0 - 2.5 t/ha every 3 to 5 years.

13) Fence off all reclaimed areas, and allow only minimal grazing over time.

14) Control rabbits and maintain vegetative ground cover.

Figure 36. Examples of tunnel erosion control (a) Poor technique. Rock rap is usually an inappropriate erosion control technique for dispersive soils. Normally rock barriers work well to trap sediment and reduce erosion. However in dispersive soils, hard surfaces such as rock are quickly bypassed i.e. upper corner of the rock structure (b) Excellent technique. Note the entire repaired area is fenced, and the whole length of the repaired tunnel is covered with topsoil and jute cloth. Sand barriers have been constructed every 20 meters down the slope.

Figure 37. Good technique. Topsoil mounding, reclaimed tunnel erosion, Brighton. Note the width of earthworks required to fix a 50cm wide tunnel, and the raised profile to shed surface water. Jute cloth would prevent surface erosion until vegetation has established.

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8.0 APPENDIX I: ANALYSIS AND CLASSIFICATION OF DISPERSIVE SOILS

(I). EXCHANGEABLE SODIUM PERCENT (ESP)

The Exchangeable Sodium Percent (ESP) is the most common analytical technique used to identify sodic or potentially dispersive soils. The ESP is determined from the ratio of exchangeable cations and is measured as method 15N1 (Rayment and Higginson 1992),

$$ESP = \frac{Na^+}{Na^+ + Mg^{2+} + K^+ + Ca^{2+}} \times 100$$

In Australia, soils with an ESP greater than 6 are classed sodic (Isbell 2002) due to their likelihood to undergo dispersion in fresh water. Highly sodic soils are classed as having an ESP greater than 15. Most North American literature however classifies soils as being sodic when the ESP exceeds 15 (Rengasamy & Churchman 1999).

(II). SODIUM ABSORPTION RATIO (SAR)

Sodium absorption ratio (SAR) is commonly used as a measure of soil sodicity in North America. In Australia it is more commonly used as a measure of sodicity in water, however its use for soil on either a saturated paste or 1:5 basis is considered useful, especially in acid soils, in which the presence of exchangeable Al+3 effects measurement of CEC (Rengasamy & Churchman 1999). Rengasamy and Olsson (1991) found that SAR of a 1:5 extract is better at predicting soil dispersion than ESP. Dispersion thresholds based on SAR1:5 are not as well established as those for ESP however if SAR1:5 is greater than 3, soils are considered sodic (Rengasamy and Olsson 1991).

$$SAR = \frac{Na^+}{((Mg^{2+} + Ca^{2+})/2)^{1/2}}$$

(III). EMERSON SOIL CRUMB TEST (AS 1289.3.8.1-1997)

The Emerson soil crumb test (AS 1289.3.8.1-1997) is an Australian Standard for the prediction of dispersive behaviour of clay soils. The Emerson test is quick and simple and can be used to assist in the rapid identification of dispersive soils. The test has three levels,

(i) Spontaneous dispersion of an air dried aggregate in deionised water,

(ii) Remoulding at near maximum field capacity and re-immersion in deionised water,

(iii) Remoulded soil is shaken in deionised water.

A number of modifications and variations to the Emerson test have sought to add subclasses to either Class 2 and Class 3 aggregates (Craze *et al.* 2003). The history and interpretation of the Emerson crumb test is discussed in Emerson (2002).

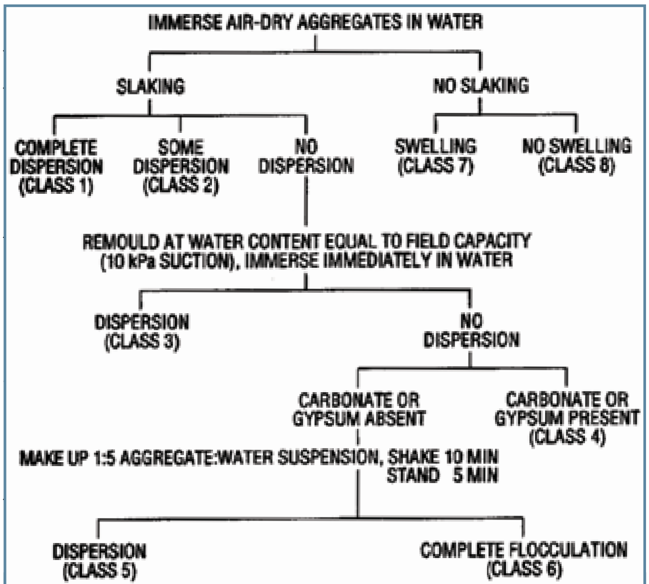

Figure 38. Emerson dispersion test procedure (AS 1289.3.8.1-1997) (Raine and Loch 2003). Soils with an Emerson ration of 1 or 2 are highly susceptible to tunnel erosion (Vacher et al. 2004).

pinhole is measured and the shape of the pinhole inspected for erosion.

(V). DISPERSION INDEX OR DOUBLE HYDROMETER TEST

The Dispersion Index has been widely used in Australia to identify soils at risk of tunnelling. Soil is shaken end over end in two separate operations, firstly in distilled water and secondly in dispersant to ensure complete dispersion. The difference between the amount of dispersion (measured as the % particles <2 microns) between the two tests is used to infer dispersion risk (Raine & Loch 2003). The dispersion index is very similar to the Double Hydrometer test (ASTM D 4211-83, 1986) routinely used in America for predicting dispersive behaviour of soils.

Figure 39. Pinhole test for compacted soils & fill. (Photo, Raine & Loch 2003).

(VI) MEASUREMENT OF CLAY DISPERSION (514.01) (RENGASAMY 2002).

The clay dispersion technique is based on the threshold electrolyte concept which takes into account the electro – osmotic pressures between clay platelets and at the soil solution. The percent of dispersed clay is determined by pipette extraction and weighing following 16 hours spontaneous dispersion and after 16 hours mechanical dispersion. The soil solution is also measured for SAR, EC and pH and the results reported as the percentage dispersed clay and the predicted dispersion class based on EC and SAR.

(VII) MEASUREMENT OF DISPERSIVE

$$\text{Dispersive if } \frac{\text{\% Particles} < 2\ \mu\text{m in dispersant \& water}}{\text{\% Particles} < 2\ \mu\text{m in distilled water}} = \leq 3.0$$

POTENTIAL (514.03) (RENGASAMY 2002).

The mechanical dispersive potential is calculated as the difference in osmotic pressure between the threshold electrolyte concentration required to flocculate clays and the ambient solution concentration. The electrolyte concentration required to flocculate the clays is determined by sequentially lowering the SAR of the solution until no clay dispersion occurs.

9.0 APPENDIX II: AMENDMENT TO EXISTING CODES OF PRACTICE & GUIDELINES

9.1 SOIL AND WATER MANAGEMENT CODE OF PRACTICE FOR HOBART REGIONAL COUNCILS (1999B).

The Soil and Water Management Code of Practice for Hobart Regional Councils (Anon 1999b) and Guidelines for Soil and Water Management (Anon 1999c) were written without an awareness of the specific issues associated with dispersive soils. Amendments (in italics) are proposed to the Water Management Code of Practice for Hobart Regional Councils (Anon 1999b) and Guidelines for Soil and Water Management (Anon 1999c).

Soil and Water Management Code of Practice for Hobart Regional Councils (Anon 1999b).

1.0 BUILDING SITES AND SMALL SUBDIVISIONS.

1.1.1 Soil and water management plans (SWMPs) are required for all developments where 250 square meters or more of ground will be disturbed. Council may vary this requirement where there is:

(iii) High likelihood that dispersive soils will be exposed or disturbed, in which case it may require a SWMP even though less than 250 square meters of ground will be disturbed.

1.1.4 Where development consent is not required, earthworks should only be undertaken without an SWMP if:

(ii) The land on which this work is undertaken is not:

- Geotechnically unstable; if soils are dispersive; and

(iv) Work will not disturb or expose dispersive soils.

1.2.1 On all sites, identify;

- Location of areas with dispersive soils or subsoils.

1.3.8 Table drains and culverts should not be constructed in locations or ways which expose dispersive soils

1.5.6 Exposed or disturbed dispersive soils will immediately be capped with 150mm topsoil.

1.5.7 Alternatives to the use of trenches for the supply of services should be considered in areas containing dispersive soils.

1.6.2 Stormwater should not be conveyed in trenches which expose dispersive soils.

1.6.3 Stormwater should not be disposed in areas which contain dispersive soils.

2.0 SUB-DIVISION CONSTRUCTION ACTIVITIES.

2.1.1 Soil and water management plans (SWMPs) are required for all developments where 250 square meters or more of ground will be disturbed. Council may vary this requirement where there is:

(iii) High likelihood that dispersive soils will be exposed or disturbed, in which case it may require a SWMP even though less than 250 square meters of ground will be disturbed.

2.1.4 Where development consent is not required, earthworks should only be undertaken without an SWMP if:

(ii) The land on which this work is undertaken is not:

- Geotechnically unstable; if soils are dispersive; and

(iv) Work will not disturb or expose dispersive soils.

2.2.3 On the map/plan identify;

- Location of areas with dispersive soils or subsoils.

2.3.4 Table drains and culverts should not be constructed in locations or ways which expose dispersive soils

2.5.6 Exposed or disturbed dispersive soils will immediately be capped with 150mm topsoil.

2.6.4 Stormwater should not be conveyed in trenches which expose dispersive soils.

2.6.5 Stormwater should not be disposed in areas which contain dispersive soils.

2.8.5 Table drains and culverts should not be constructed in locations or ways which expose dispersive soils.

3.0 CIVIL INFRASTRUCTURE WORKS.

3.1.1 Soil and water management plans (SWMPs) are required for all developments where 250 square meters or more of ground will be disturbed. Council may vary this requirement where there is:

(iii) High likelihood that dispersive soils will be exposed or disturbed, in which case it may require a SWMP even though less than 250 square meters of ground will be disturbed.

3.1.6 Where development consent is not required, earthworks should only be undertaken without an SWMP if:

(iv) Work will not disturb or expose dispersive soils.

3.2.3 On the map/plan identify;

- Location of areas with dispersive soils or subsoils.

3.3.4 Table drains and culverts should not be constructed in locations or ways which expose dispersive soils

3.5.11 Exposed or disturbed dispersive soils will immediately be capped with 150mm topsoil.

3.5.12 Alternatives to the use of trenches for the supply of services should be considered in areas containing dispersive soils.

3.6.4 Stormwater should not be conveyed in trenches which expose dispersive soils.

3.6.5 Stormwater should not be disposed in areas which contain dispersive soils.

3.8.4 Table drains and culverts should not be constructed in locations or ways which expose dispersive soils.

9.2 GUIDELINES FOR SOIL AND WATER MANAGEMENT (ANON 1999C)

The following section on dispersive soils should be appended to the guidelines.

What are Dispersive Soils.

- Dispersive soils disperse or appear to 'dissolve' in water, forming a cloudy ring or halo of detached soil particles.
- Dispersive soils are usually sodic, containing greater than 6% sodium within the clay structure.
- Dispersive soils are usually derived from sedimentary rocks.
- Dispersive soils occur in all municipalities in southern Tasmania.

Issues with Dispersive Soils

- Result in tunnel erosion.
- Result in damage to infrastructure including foundations, roads and septic systems.
- Often responsible for dam collapse.
- Impact on environment including considerable turbidity in waterways.
- Usually considerable damage has occurred before tunnel erosion is detected.
- Potential liability risk.

Management of Dispersive Soils

Should Do

- Apply gypsum to potentially dispersive soils.
- Cover exposed dispersive soils with topsoil.
- Vegetate all bare areas with vigorous pasture.
- Seek profession geotechnical advice before commencing construction works including dam construction, roads and building foundations.

Should Not Do.

- Expose dispersive subsoils to rain.
- Allow water to pond on dispersive soils.
- Concentrate stormwater in drainage lines containing dispersive soils.
- Use table drains, trenches or cut and fill construction techniques in areas containing dispersive soils.
- Scalp or extract topsoil from areas with dispersive subsoils.

Tasmania
Explore the possibilities

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