EPA/600/R-93/182
September 1993

Technical Guidance Document:

QUALITY ASSURANCE AND QUALITY CONTROL FOR WASTE CONTAINMENT FACILITIES

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Cooperative Agreement No. CR-815546-01-0

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Chapter 2

Compacted Soil Liners

2.1 Introduction and Background

2.1.1 Types of Compacted Soil Liners

Compacted soil liners have been used for many years as engineered hydraulic barriers for waste containment facilities. Some liner and cover systems contain a single compacted soil liner, but others may contain two or more compacted soil liners. Compacted soil liners are frequently used in conjunction with geomembranes to form a *composite liner*, which usually consists of a geomembrane placed directly on the surface of a compacted soil liner. Examples of soil liners used in liner and cover systems are shown in Fig. 2.1.

Compacted soil liners are composed of clayey materials that are placed and compacted in layers called *lifts*. The materials used to construct soil liners include natural mineral materials (natural soils), bentonite-soil blends, and other material

2.1.1.1 Natural Mineral Materials

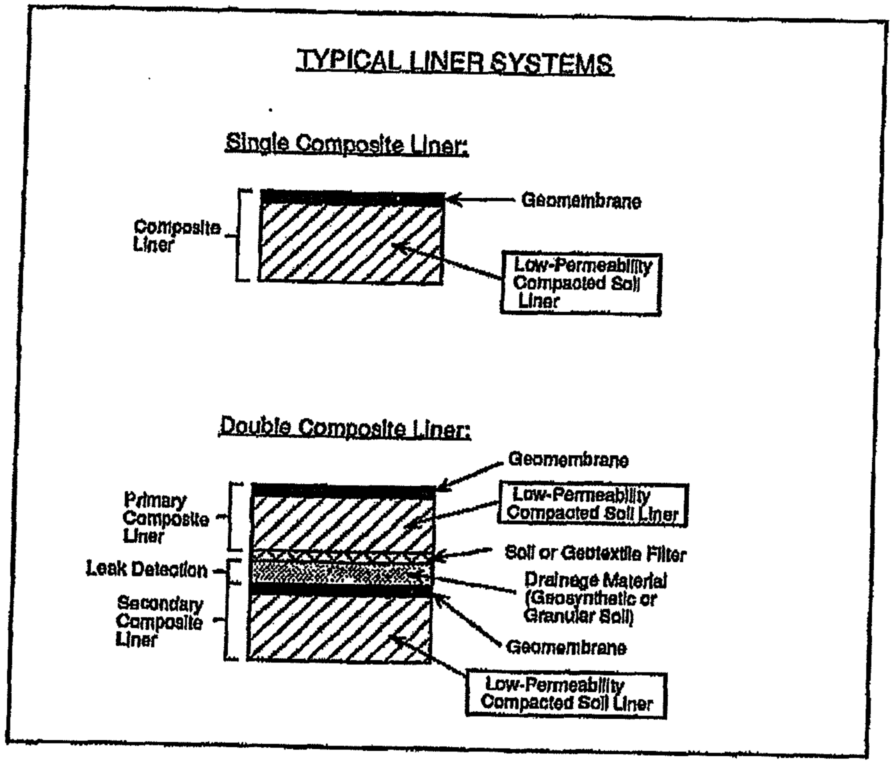
The most common type of compacted soil liner is one that is constructed from naturally occurring soils that contain a significant quantity of clay. Soils are usually classified as CL, CH, or SC soils in the Unified Soil Classification System (USCS) and ASTM D-2487. Soil liner materials are excavated from locations called *borrow pits*. These borrow areas are located either on the site or offsite. The soil in the borrow pit may be used directly without processing or may be processed to alter the water content, break down large pieces of material, or remove oversized particles. Sources of natural soil liner materials include lacustrine deposits, glacial tills, aeolian materials, deltaic deposits, residual soils, and other types of soil deposits. Weakly cemented or highly weathered rocks, e.g., mudstones and shales, can also be used for soil liner materials, provided they are processed properly.

2.1.1.2 Bentonite-Soil Blends

If the soils found in the vicinity of a waste disposal facility are not sufficiently clayey to be suitable for direct use as a soil liner material, a common practice is to blend natural soils available on or near a site with bentonite. The term *bentonite* is used in different ways by different people. For purposes of this discussion, bentonite is any commercially processed material that is composed primarily of the mineral smectite. Bentonite may be supplied in granular or pulverized form. The dominant adsorbed cation of commercial bentonite is usually sodium or calcium, although the sodium form is much more commonly used for soil sealing applications. Bentonite is mixed with native soils either in thin layers or in a pugmill.

2.1.1.3 Other

Other materials have occasionally been used for compacted soil liners. For example, bentonite may be blended with flyash to form a liner under certain circumstances. Modified soil minerals and commercial additives, e.g., polymers, have sometimes been used.



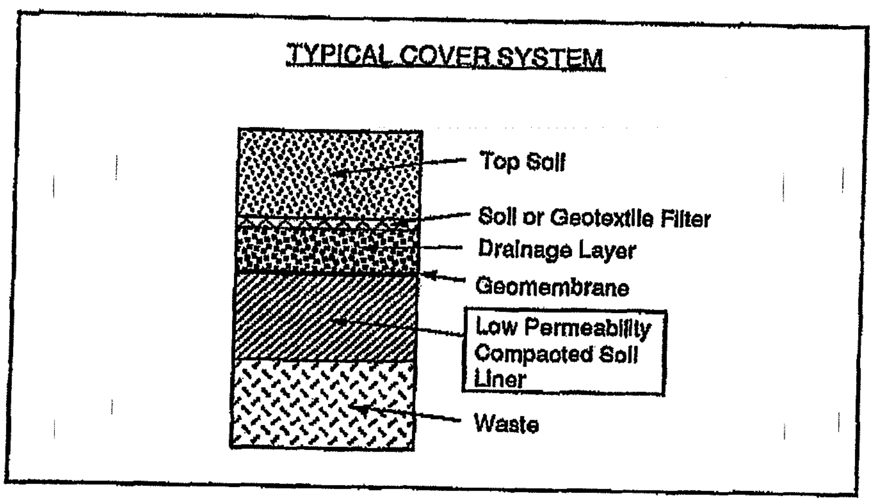


Figure 2.1 - Examples of Compacted Soil Liners in Liner and Cover Systems

2.1.2 Critical CQC and CQA Issues

The CQC and CQA processes for soil liners are intended to accomplish three objectives:

1. Ensure that soil liner materials are suitable.

2. Ensure that soil liner materials are properly placed a. .. compacted.

3. Ensure that the completed liner is properly protected.

Some of these issues, such as protection of the liner from desiccation after completion, simply require application of common-sense procedures. Other issues, such preprocessing of materials, are potentially much more complicated because, depending on the material, many construction steps may be involved. Furthermore, tests alone will not adequately address many of the critical CQC and CQA issues -- visual observations by qualified personnel, supplemented by intelligently selected tests, provide the best approach to ensure quality in the constructed soil liner.

As discussed in Chapter 1, the objective of CQA is to ensure that the final product meets specifications. A detailed program of tests and observations is necessary to accomplish this objective. The objective of CQC is to control the manufacturing or construction process to meet project specifications. With geosynthetics, the distinction between CQC and CQA is obvious: the geosynthetics installer performs CQC while an independent organization conducts CQA. However, CQC and CQA activities for soils are more closely linked than in geosynthetics installation. For example, on many earthwork projects the CQA inspector will typically determine the water content of the soil and report the value to the contractor; in effect, the CQA inspector is also providing CQC input to the contractor. On some projects, the contractor is required to perform extensive tests as part of the CQC process, and the CQA inspector performs tests to check or confirm the results of CQC tests.

The lack of clearly separate roles for CQC and CQA inspectors in the earthwork industry is a result of historic practices and procedures. This chapter is focused on CQA procedures for soil liners, but the reader should understand that CQA and CQC practices are often closely linked in earthwork. In any event, the QA plan should clearly establish QA procedures and should consider whether there will be QC tests and observations to complement the QA process.

2.1.3 Liner Requirements

The construction of soil liners is a challenging task that requires many careful steps. A blunder concerning any one detail of construction can have disastrous impacts upon the hydraulic conductivity of a soil liner. For example, if a liner is allowed to desiccate, cracks might develop that could increase the hydraulic conductivity of the liner to above the specified requirement.

As stated in Section 2.1.2, the CQC and CQA processes for soil liners essentially consist of using suitable materials, placing and compacting the materials properly, and protecting the completed liner. The steps required to fulfill these requirements may be summarized as follows:

1. The subgrade on which the soil liner will be placed should be properly prepared.

2. The materials employed in constructing the soil liner should be suitable and should conform to the plans and specifications for the project.

3. The soil liner material should be preprocessed, if necessary, to adjust the water content, to remove oversized particles, to break down clods of soil, or to add amendments such as bentonite.

4. The soil should be placed in lifts of appropriate thickness and then be properly remolded and compacted.

5. The completed soil liner should be protected from damage caused by desiccation or freezing temperatures.

6. The final surface of the soil liner should be properly prepared to support the next layer that will be placed on top of the soil liner.

The six steps mentioned above are described in more detail in the succeeding subsections to provide the reader with a general introduction to the nature of CQC and CQA for soil liners. Detailed requirements are discussed later.

2.1.3.1 Subgrade Preparation

The subgrade on which a soil liner is placed should be properly prepared, i.e., provide adequate support for compaction and be free from mass movements. The compacted soil liner may be placed on a natural or geosynthetic material, depending on the particular design and the individual component in the liner or cover system. If the soil liner is the lowest component of the liner system, native soil or rock forms the subgrade. In such cases the subgrade should be compacted to eliminate soft spots. Water should be added or removed as necessary to produce a suitably firm subgrade per specification requirements. In other instances the soil liner may be placed on top of geosynthetic components of the liner system, e.g., a geotextile. In such cases, the main concern is the smoothness of the geosynthetic on which soil is placed and conformity of the geosynthetic to the underlying material (e.g., no bridging over ruts left by vehicle traffic).

Sometimes it is necessary to "tie in" a new section of soil liner to an old one, e.g., when a landfill is being expanded laterally. It is recommended that a lateral excavation be made about 3 to 6 m (10 to 20 ft) into the existing soil liner, and that the existing liner be stair-stepped as shown in Fig. 2.2 to tie the new liner into the old one. The surface of each of the steps in the old liner should be scarified to maximize bonding between the new and old sections.

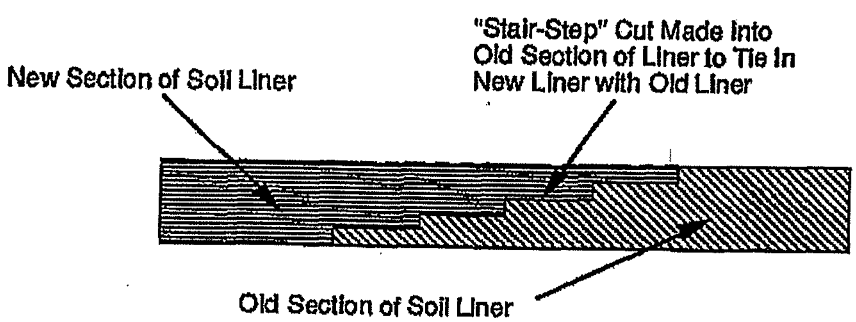


Figure 2.2 - Tie-In of New Soil Liner to Existing Soil Liner

2.1.3.2 Material Selection

Soil liner materials are selected so that a low hydraulic conductivity will be produced after the soil is remolded and compacted. Although the performance specification is usually hydraulic conductivity, CQA considerations dictate that restrictions be placed on certain properties of the soil used to build a liner. For example, limitations may be placed on the liquid limit, plastic limit, plasticity index, percent fines, and percent gravel allowed in the soil liner material.

The process of selecting construction materials and verifying the suitability of the materials varies from project to project. In general, the process is as follows:

1. A potential borrow source is located and explored to determine the vertical and lateral extent of the source and to obtain representative samples, which are tested for properties such as liquid limit, plastic limit, percent fines, etc.

2. Once construction begins, additional CQC and CQA observations and tests may be performed in the borrow pit to confirm the suitability of materials being removed.

3. After a lift of soil has been placed, additional CQA tests should be performed for final verification of the suitability of the soil liner materials.

On some projects, the process may be somewhat different. For example, a materials company may offer to sell soil liner materials from a commercial pit, in which case the first step listed above (location of borrow source) is not relevant.

A variety of tests is performed at various stages of the construction process to ensure that the soil liner material conforms with specifications. However, tests alone will not necessarily ensure an adequate material -- observations by qualified CQA inspectors are essential to confirm that deleterious materials (such as stones or large pieces of organic or other deleterious matter) are not present in the soil liner material.

2.1.3.3 Preprocessing

Some soil liner materials must be processed prior to use. The principal preprocessing steps that may be required include the following:

1. Drying of soil that is too wet.

2. Wetting of soil that is too dry.

3. Removal of oversized particles.

4. Pulverization of clods of soil.

5. Homogenization of nonuniform soil.

6. Addition of bentonite.

Tests are performed by CQA personnel to confirm proper preprocessing, but visual observations by CQC and CQA personnel are needed to confirm that proper procedures have been followed and that the soil liner material has been properly preprocessed.

2.1.3.4 Placement, Remolding, and Compaction

Soil liners are placed and compacted in lifts. The soil liner material must first be placed in a loose lift of appropriate thickness. If a loose lift is too thick, adequate compactive energy may not be delivered to the bottom of a lift.

The type and weight of compaction equipment can have an important influence upon the hydraulic conductivity of the constructed liner. The CQC/CQA program should be designed to ensure that the soil liner material will be properly placed, remolded, and compacted as described in the plans and specifications for the project.

2.1.3.5 Protection

The completed soil liner must be protected from damage caused by desiccation or freezing temperatures. Each completed lift of the soil liner, as well as the completed liner, must be protected.

2.1.3.6 Final Surface Preparation

The surface of the liner must be properly compacted and smoothed to serve as a foundation for an overlying geomembrane liner or other component of a liner or cover system. Verification of final surface preparation is an important part of the CQA process.

2.1.4 Compaction Requirements

One of the most important aspects of constructing soil liners that have low hydraulic conductivity is the proper remolding and compaction of the soil. Background information on soil compaction is presented in this subsection.

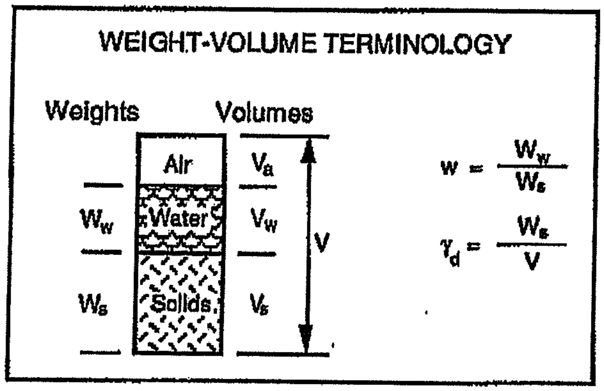
2.1.4.1 Compaction Curve

A compaction curve is developed by preparing several samples of soil at different water contents and then sequentially compacting each of the samples into a mold of known volume with a specified compaction procedure. The total unit weight (γ), which is also called the wet density, of each specimen is determined by weighing the compacted specimen and dividing the total weight by the total volume. The water content (w) of each compacted specimen is determined by oven drying the specimen. The dry unit weight (γ_d), which is sometimes called the dry density, is calculated as follows:

$$\gamma_d = \gamma/(1 + w) \tag{2.1}$$

The (w, γ_d) points are plotted and a smooth curve is drawn between the points to define the compaction curve (Fig. 2.3). Judgment rather than an analytic algorithm is usually employed to draw the compaction curve through the measured points.

The *maximum dry unit weight* ($\gamma_{d,max}$) occurs at a water content that is called the *optimum water content*, w_{opt} (Fig. 2.3). The main reason for developing a compaction curve is to determine the optimum water content and maximum dry unit weight for a given soil and compaction procedure.



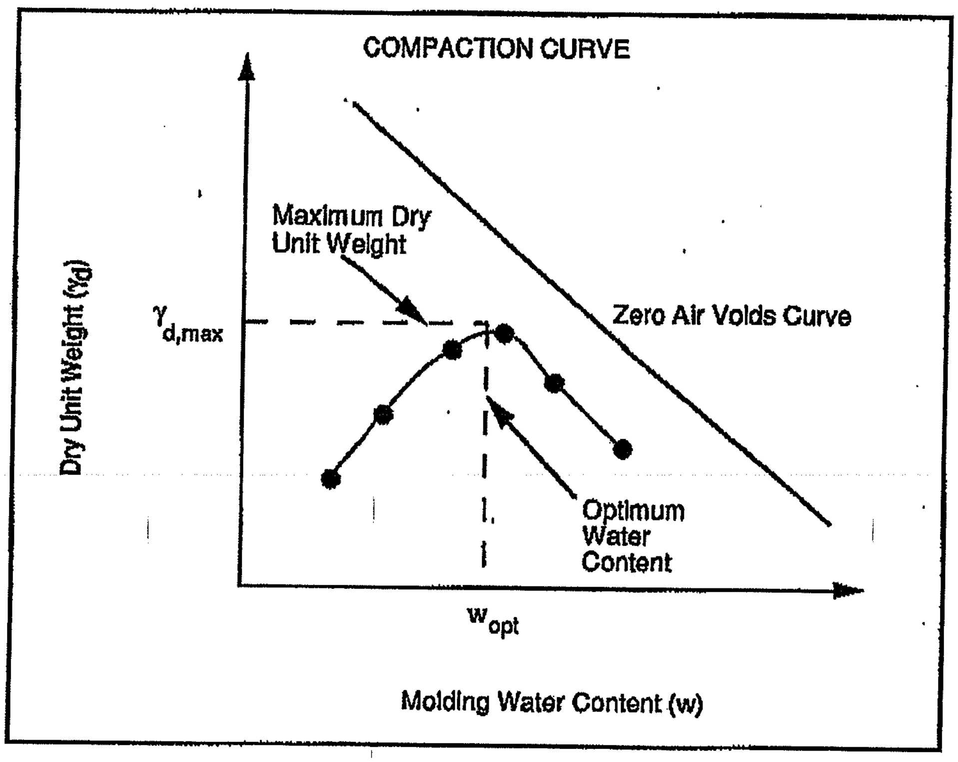


Figure 2.3 - Compaction Curve

The *zero air voids curve* (Fig. 2.3), also known as the *100% saturation curve,* is a curve that relates dry unit weight to water content for a saturated soil that contains no air. The equation for the zero air voids curve is:

$$\gamma_d = \gamma_w/[w + (1/G_s)] \qquad (2.2)$$

where G_s is the specific gravity of solids (typically 2.6 to 2.8) and γ_w is the unit weight of water. If the soil's specific gravity of solids changes, the zero air voids curve will also change. Theoretically, no points on a plot of dry unit weight versus water content should lie above the zero air voids curve, but in practice some points usually lie slightly above the zero air voids curve as a result of soil variability and inherent limitations in the accuracy of water content and unit weight measurements (Schmertmann, 1989).

Benson and Boutwell (1992) summarize the maximum dry unit weights and optimum water content measured on soil liner materials from 26 soil liner projects and found that the degree of saturation at the point of (w_{opt}, $\gamma_{d,max}$) ranged from 71% to 98%, based on an assumed G_s value of 2.75. The average degree of saturation at the optimum point was 85%.

2.1.4.2 Compaction Tests

Several methods of laboratory compaction are commonly employed. The two procedures that are most commonly used are standard and modified compaction. Both techniques usually involve compacting the soil into a mold having a volume of 0.00094 m^3 (1/30 ft^3). The number of lifts, weight of hammer, and height of fall are listed in Table 2.1. The compaction tests are sometimes called *Proctor* tests after Proctor, who developed the tests and wrote about the procedures in several 1933 issues of Engineering News Record. Thus, the compaction curves are sometimes called Proctor curves, and the maximum dry unit weight may be termed the *Proctor density*.

Table 2.1 - Compaction Test Details

Compaction Procedure	Number of Lifts	Weight of Hammer	Height of Fall	Compactive Energy
Standard	3	24.5N (5.5 lbs)	305 mm (12 in.)	594 kN-m/m^3 (12,375 ft-lb/ft^3)
Modified	5	44.5N (10 lbs)	457 mm (18 in.)	2,693 kN-m/m^3 (56,250 ft-lb/ft^3)

Proctor's original test, now frequently called the *standard Proctor compaction test*, was developed to control compaction of soil bases for highways and airfields. The maximum dry unit weights attained from the standard Proctor compaction test were approximately equal to unit weights observed in the field on well-built fills using compaction equipment available in the 1920s and 1930s. During World War II, much heavier compaction equipment was developed and the unit weights attained from field compaction sometimes exceeded the laboratory values. Proctor's original procedure was modified by increasing compactive energy. By today's standards:

- Standard Compaction (ASTM D-698) produces maximum dry unit weights approximately equal to field dry unit weights for soils that are well compacted using modest-sized compaction equipment.

- Modified Compaction (ASTM D-1557) produces maximum dry unit weights approximately equal to field dry unit weights for soils that are well compacted using the heaviest compaction equipment available.

2.1.4.3 Percent Compaction

The compaction test is used to help CQA personnel to determine: 1) whether the soil is at the proper water content for compaction, and 2) whether the soil has received adequate compactive effort. Field CQA personnel will typically measure the water content of the field-compacted soil (w) and compare that value with the optimum water content (w_{opt}) from a laboratory compaction test. The construction specifications may limit the value of w relative to w_{opt}, e.g., specifications may require w to be between 0 and +4 percentage points of w_{opt}. Field CQC personnel should measure the water content of the soil prior to remolding and compaction to ensure that the material is at the proper water content before the soil is compacted. However, experienced earthwork personnel can often tell if the soil is at the proper water content from the look and feel of the soil. Field CQA personnel should measure the water content and unit weight after compaction to verify that the water content and dry unit weight meet specifications. Field CQA personnel often compute the percent compaction, P, which is defined as follows:

$$P = \gamma_d/\gamma_{d,max} \times 100\% \qquad (2.3)$$

where γ_d is the dry unit weight of the field-compacted soil. Construction specifications often stipulate a minimum acceptable value of P.

In summary, the purpose of the laboratory compaction test as applied to CQC and CQA is to provide water content (w_{opt}) and dry unit weight ($\gamma_{d,max}$) reference points. The actual water content of the field-compacted soil liner may be compared to the optimum value determined from a specified laboratory compaction test. If the water content is not in the proper range, the engineering properties of the soil are not likely to be in the range desired. For example, if the soil is too wet, the shear strength of the soil may be too low. Similarly, the dry unit weight of the field-compacted soil may be compared to the maximum dry unit weight determined from a specified laboratory compaction test. If the percent compaction is too low, the soil has probably not been adequately compacted in the field. Compaction criteria may also be established in ways that do not involve percent compaction, as discussed later, but one way or another, the laboratory compaction test provides a reference point.

2.1.4.4 Estimating Optimum Water Content and Maximum Dry Unit Weight

Many CQA plans require that the water content and dry unit weight of the field-compacted soil be compared to values determined from laboratory compaction tests. Compaction tests are a routine part of nearly all CQA programs. However, from a practical standpoint, performing compaction tests introduces two problems:

1. A compaction test often takes 2 to 4 days to complete -- field personnel cannot wait for the completion of a laboratory compaction test to make "pass-fail" decisions.

2. The soil will inevitably be somewhat variable -- the optimum water content and maximum dry unit weight will vary. The values of w_{opt} and $\gamma_{d,max}$ appropriate for one location may not be appropriate for another location. This has been termed a "mismatch" problem (Noorany, 1990).

Because dozens (sometimes hundreds) of field water content and density tests are performed, it is impractical to perform a laboratory compaction test each and every time a field measurement of water content and density is obtained. Alternatively, simpler techniques for estimating the maximum dry unit weight are almost always employed for rapid field CQA assessments. These techniques are subjective assessment, one-point compaction test, and three-point compaction test.

2.1.4.4.1 Subjective Assessment

Relatively homogeneous fill materials produce similar results when repeated compaction tests are performed on the soil. A common approach is to estimate optimum water content and maximum dry unit weight based on the results of previous compaction tests. The results of at least 2 to 3 laboratory compaction tests should be available from tests on borrow soils prior to actual compaction of any soil liner material for a project. With subjective assessment, CQA personnel estimate the optimum water content and maximum dry unit weight based upon the results of the previously-completed compaction tests and their evaluation of the soil at a particular location in the field. Slight variations in the composition of fill materials will cause only slight variations in w_{opt} and $\gamma_{d,max}$. As an approximate guide, a relatively homogeneous borrow soil would be considered a material in which w_{opt} does not vary by more than ± 3 percentage points and $\gamma_{d,max}$ does not vary by more than ± 0.8 kN/ft^3 (5 pcf). The optimum water content and maximum dry unit weight should not be estimated in this manner if the soil is heterogeneous -- too much guess work and opportunity for error would exist.

2.1.4.4.2 One-Point Compaction Test

The results of several complete compaction tests should always be available for a particular borrow source prior to construction, and the data base should expand as a project progresses and additional compaction tests are performed. The idea behind a one-point compaction test is shown in Fig. 2.4. A sample of soil is taken from the field and dried to a water content that appears to be just dry of optimum. An experienced field technician can usually tell without much difficulty when the water content is just dry of optimum. The sample of soil is compacted into a mold of known volume according to the compaction procedure relevant to a particular project, e.g., ASTM D-698 or D-1557. The weight of the compacted specimen is measured and the total unit weight is computed. The sample is dried using one of the rapid methods of measurement discussed later to determine water content. Dry unit weight is computed from Eq. 2.2. The water content-dry unit weight point from the one-point compaction test is plotted as shown in Fig. 2.4 and used in conjunction with available compaction curves to estimate w_{opt} and $\gamma_{d,max}$. One assumes that the shape of the compaction is similar to the previously-developed compaction curves and passes through the one point that has been determined.

The dashed curve in Fig. 2.4 is the estimated compaction curve. The one-point compaction test is commonly used for variable soils. In extreme cases, a one-point compaction test may be required for nearly all field water content and density measurements for purposes of computing percent compaction. However, if the material is so variable to require a one-point compaction test for nearly all field density measurements, the material is probably too variable to be suitable for use in a soil liner. The best use of the one-point compaction test is to assist with estimation of the optimum water content and maximum dry unit weight for questionable materials and to fill in data gaps when results of complete compaction tests are not available quickly enough.

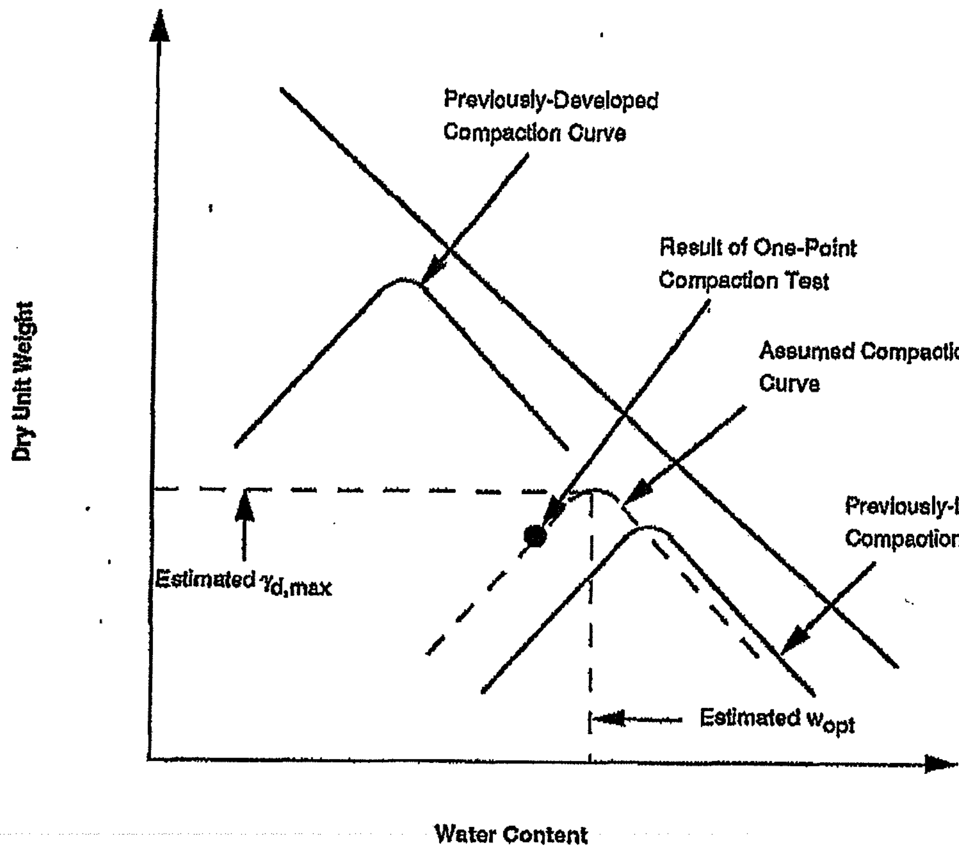


Figure 2.4 - One-Point Compaction Test

2.1.4.4.3 Three-Point Compaction Test (ASTM D-5080)

A more reliable technique than the one-point compaction test for estimating the optimum water content and maximum dry unit weight is to use a minimum of three compaction points to define a curve rather than relying on a single compaction point. A representative sample of soil is obtained from the field at the same location where the in-place water content and dry unit weight have been measured. The first sample of soil is compacted at the field water content. A second sample is prepared at a water content two percentage points wetter than the first sample and is compacted. However, for extremely wet soils that are more than 2% wet of optimum (which is often the case for soil liner materials), the second sample should be dried 2% below natural water content. Depending on the outcome of this compaction test, a third sample is prepared at a water content either two percentage points dry of the first sample or two percentage points wet of the second sample (or, for wet soil liners, 2 percentage points dry of the second sample). A parabola is fitted to the three compaction data points and the optimum water content and maximum dry unit weight are determined from the equation of the best-fit parabola. This technique is significantly more time consuming than the one-point compaction test but offers 1) a standard ASTM procedure and 2) greater reliability and repeatability in estimated w_{opt} and $\gamma_{d,max}$.

2.1.4.5 Recommended Procedure for Developing Water Content-Density Specification

One of the most important aspects of CQC and CQA for soil liners is documentation of the water content and dry unit weight of the soil immediately after compaction. Historically, the method used to specify water content and dry unit weight has been based upon experience with structural fill. Design engineers often require that soil liners be compacted within a specified range of water content and to a minimum dry unit weight. The "Acceptable Zone" shown in Fig. 2.5 represents the zone of acceptable water content/dry unit weight combinations that is often prescribed. The shape of the Acceptable Zone shown in Fig. 2.5 evolved empirically from construction practices applied to roadway bases, structural fills, embankments, and earthen dams. The specification is based primarily upon the need to achieve a minimum dry unit weight for adequate strength and limited compressibility. As discussed by Mundell and Bailey (1985), Boutwell and Hedges (1989), and Daniel and Benson (1990), this method of specifying water content and dry unit weight is not necessarily the best method for compacted soil liners.

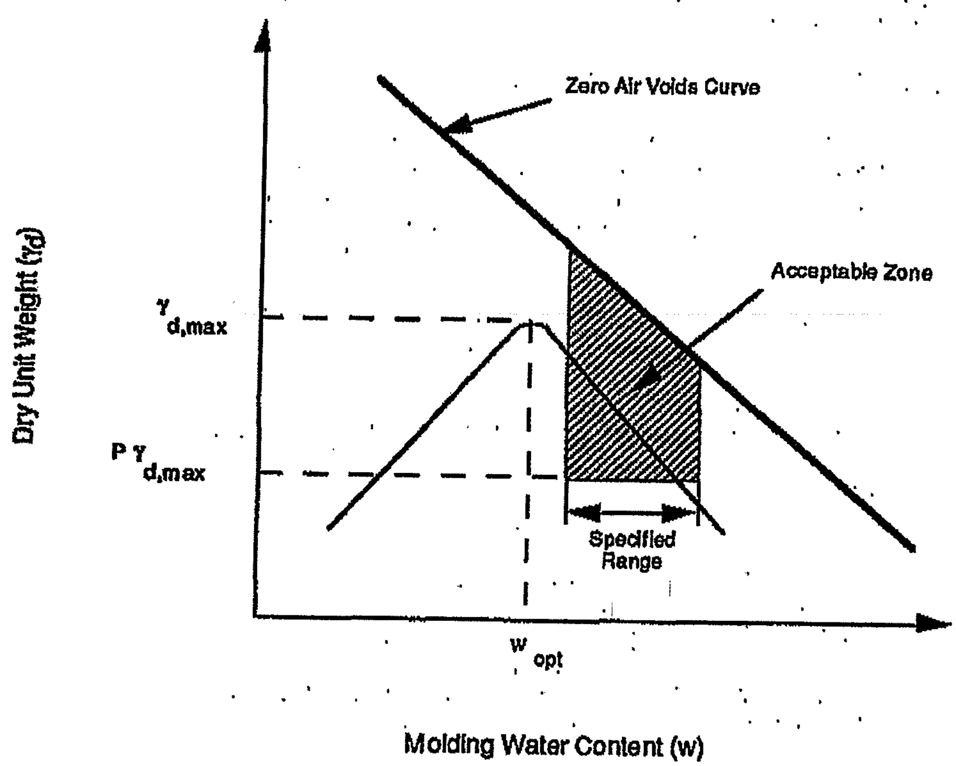


Figure 2.5 - Form of Water Content-Dry Unit Weight Specification Often Used in the Past

The recommended approach is intended to ensure that the soil liner will be compacted to a water content and dry unit weight that will lead to low hydraulic conductivity and adequate engineering performance with respect to other considerations, e.g., shear strength. Rational specification of water content/dry unit weight criteria should be based upon test data developed for each particular soil. Field test data would be better than laboratory data, but the cost of determining compaction criteria in the field through a series of test sections would almost always be prohibitive. Because the compactive effort will vary in the field, a logical approach is to select several compactive efforts in the laboratory that span the range of compactive effort that might be anticipated in the field. If this is done, the water content/dry unit weight criterion that evolves would be expected to apply to any reasonable compactive effort.

For most earthwork projects, modified Proctor effort represents a reasonable upper limit on the compactive effort likely to be delivered to the soil in the field. Standard compaction effort (ASTM D-698) likely represents a medium compactive effort. It is conceivable that soil in some locations will be compacted with an effort less than that of standard Proctor compaction. A reasonable lower limit of compactive energy is the "reduced compaction" procedure in which standard compaction procedures (ASTM D-698) are followed except that only 15 drops of the hammer per lift are used instead of the usual 25 drops. The reduced compaction procedure is the same as the 15 blow compaction test described by the U.S. Army Corps of Engineers (1970). The reduced compactive effort is expected to correspond to a reasonable minimum level of compactive energy for a typical soil liner or cover. Other compaction methods, e.g., kneading compaction, could be used. The key is to span the range of compactive effort expected in the field with laboratory compaction procedures.

One satisfactory approach is as follows:

1. Prepare and compact soil in the laboratory with modified, standard, and reduced compaction procedures to develop compaction curves as shown in Fig. 2.6a. Make sure that the soil preparation procedures are appropriate; factors such as clod size reduction may influence the results (Benson and Daniel, 1990). Other compaction procedures can be used if they better simulate field compaction and span the range of compactive effort expected in the field. Also, as few as two compaction procedures can be used if field construction procedures make either the lowest or highest compactive energy irrelevant.

2. The compacted specimens should be permeated, e.g., per ASTM D-5084. Care should be taken to ensure that permeation procedures are correct, with important details such as degree of saturation and effective confining stress carefully selected. The measured hydraulic conductivity should be plotted as a function of molding water content as shown in Fig. 2.6b.

3. As shown in Fig. 2.6c, the dry unit weight/water content points should be replotted with different symbols used to represent compacted specimens that had hydraulic conductivities greater than the maximum acceptable value and specimens with hydraulic conductivities less than or equal to the maximum acceptable value. An "Acceptable Zone" should be drawn to encompass the data points representing test results meeting or exceeding the design criteria. Some judgment is usually necessary in constructing the Acceptable Zone from the data points. Statistical criteria (e.g., Boutwell and Hedges, 1989) may be introduced at this stage.

4. The Acceptable Zone should be modified (Fig. 2.6d) based on other considerations such as shear strength. Additional tests are usually necessary in order to define the acceptable range of water content and dry unit weight that satisfies both hydraulic conductivity and shear strength criteria. Figure 2.7 illustrates how one might overlap Acceptable Zones defined from hydraulic conductivity and shear strength considerations to define a single Acceptable Zone. The same procedure can be applied to take into consideration other factors such as shrink/swell potential relevant to any particular project.

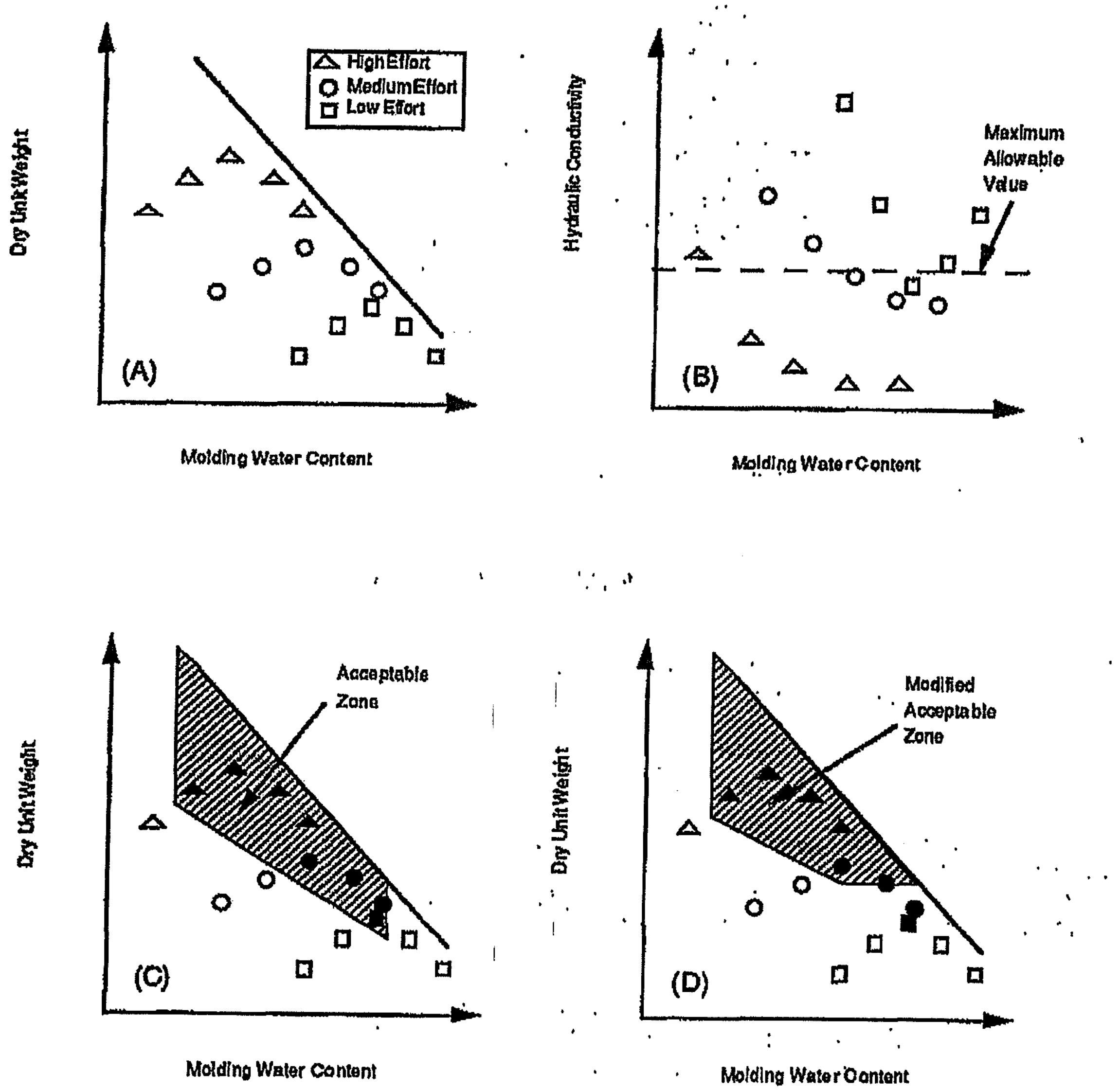


Figure 2.6 - Recommended Procedure to Determine Acceptable Zone of Water Content/Dry Unit Weight Values Based Upon Hydraulic Conductivity Considerations (after Daniel and Benson, 1990).

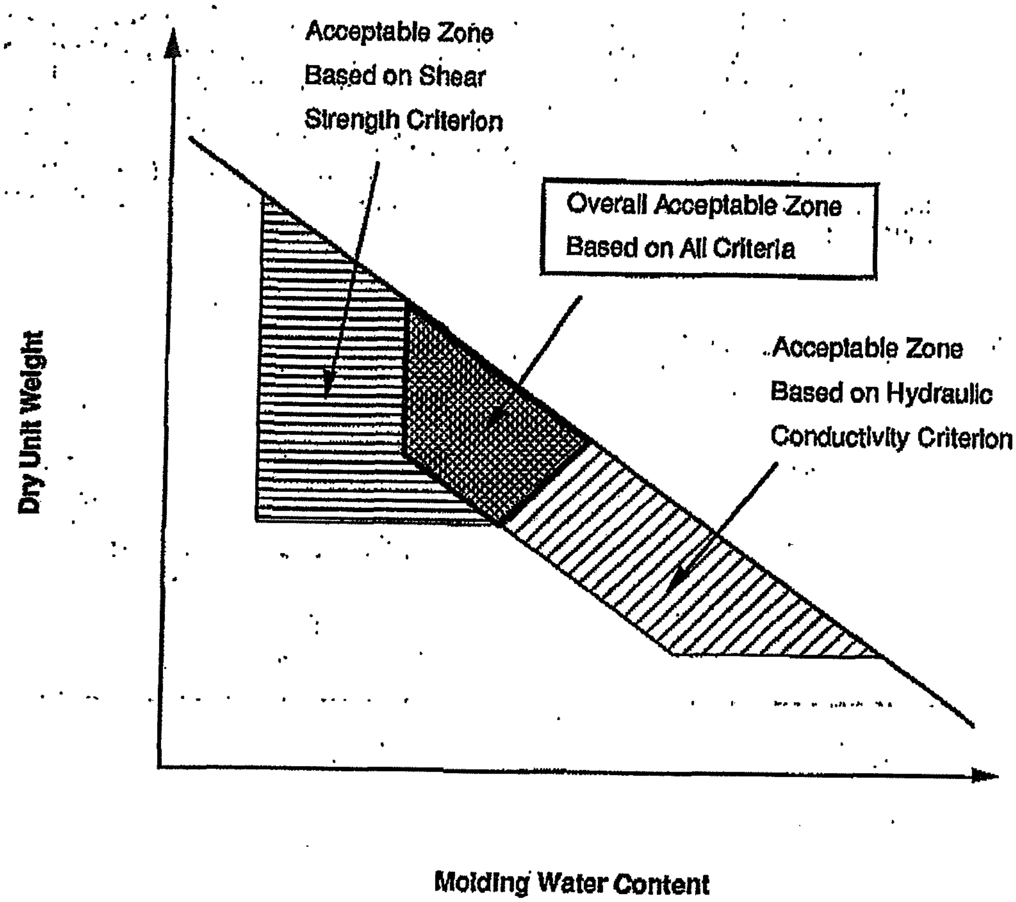


Figure 2.7 - Acceptable Zone of Water Content/Dry Unit Weights Determined by Superposing Hydraulic Conductivity and Shear Strength Data (after Daniel and Benson, 1990).

The same general procedure just outlined may also be used for soil-bentonite mixtures. However, to keep the scope of testing reasonable, the required amount of bentonite should be determined before the main part of the testing program is initiated. The recommended procedure for soil-bentonite mixes may be summarized as follows:

1. The type, grade, and gradation of bentonite that will be used should be determined. This process usually involves estimating costs from several potential suppliers. A sufficient quantity of the bentonite likely to be used for the project should be obtained and tested to characterize the bentonite (characterization tests are discussed later).

2. A representative sample of the soil to which the bentonite will be added should be obtained.

3. Batches of soil-bentonite mixtures should be prepared by blending in bentonite at several percentages, e.g., 2%, 4%, 6%, 8%, and 10% bentonite. Bentonite content is defined as the weight or mass of bentonite divided by the weight or mass of soil mixed with bentonite. For instance, if 5 kg of bentonite are mixed with 100 kg of soil, the bentonite content is 5%. Some people use the gross weight of bentonite rather than oven dry weight. Since air-dry bentonite usually contains 10% to 15% hygroscopic water by weight, the use of oven-dry, air-dry, or damp weight can make a difference in the percentage. Similarly, the weight of soil may be defined as either moist or dry (air- or oven-dry) weight. The contractor would rather work with total (moist) weights since the materials used in forming a soil-bentonite blend do contain some water. However, the engineering characteristics are controlled by the relative amounts of dry materials. A dry-weight basis is generally recommended for definition of bentonite content, but CQC and CQA personnel must recognize that the project specifications may or may not be on a dry-weight basis.

4. Develop compaction curves for each soil-bentonite mixture prepared from Step 3 using the method of compaction appropriate to the project, e.g., ASTM D-698 or ASTM D-1557.

5. Compact samples at 2% wet of optimum for each percentage of bentonite using the same compaction procedure employed in Step 4.

6. Permeate the soils prepared from Step 5 using ASTM D-5084 or some other appropriate test method. Graph hydraulic conductivity versus percentage of bentonite.

7. Decide how much bentonite to use based on the minimum required amount determined from Step 6. The minimum amount of bentonite used in the field should always be greater than the minimum amount suggested by laboratory tests because mixing in the field is usually not as thorough as in the laboratory. Typically, the amount of bentonite used in the field is one to four percentage points greater than the minimum percent bentonite indicated by laboratory tests.

8. A master batch of material should be prepared by mixing bentonite with a representative sample of soil at the average bentonite content expected in the field. The procedures described earlier for determining the Acceptable Zone of water content and dry unit weight are then applied to the master batch.

2.1.5 Test Pads

Test pads are sometimes constructed and tested prior to construction of the full-scale compacted soil liner. The test pad simulates conditions at the time of construction of the soil liner. If conditions change, e.g., as a result of emplacement of waste materials over the liner, the properties of the liner will change in ways that are not normally simulated in a test pad. The objectives of a test pad should be as follows:

1. To verify that the materials and methods of construction will produce a compacted soil liner that meets the hydraulic conductivity objectives defined for a project, hydraulic conductivity should be measured with techniques that will characterize the large-scale hydraulic conductivity and identify any construction defects that cannot be observed with small-scale laboratory hydraulic conductivity tests.

2. To verify that the proposed CQC and CQA procedures will result in a high-quality soil liner that will meet performance objectives.

3. To provide a basis of comparison for full-scale CQA: if the test pad meets the performance objectives for the liner (as verified by appropriate hydraulic conductivity tests) and the full-scale liner is constructed to standards that equal or exceed those used in building the test pad, then assurance is provided that the full-scale liner will also meet performance objectives.

4. If appropriate, a test pad provides an opportunity for the facility owner to demonstrate that unconventional materials or construction techniques will lead to a soil liner that meets performance objectives.

In terms of CQA, the test pad can provide an extremely powerful tool to ensure that performance objectives are met. The authors recommend a test pad for any project in which failure of the soil liner to meet performance objectives would have a potentially important, negative environmental impact.

A test pad need not be constructed if results are already available for a particular soil and construction methodology. By the same token, if the materials or methods of construction change, an additional test pad is recommended to test the new materials or construction procedures. Specific CQA tests and observations that are recommended for the test pad are described later in Section 2.10.

2.2 Critical Construction Variables that Affect Soil Liners

Proper construction of compacted soil liners requires careful attention to construction variables. In this section, basic principles are reviewed to set the stage for discussion of detailed CQC and CQA procedures.

2.2.1 Properties of the Soil Material

The construction specifications place certain restrictions on the materials that can be used in constructing a soil liner. Some of the restrictions are more important than others, and it is important for CQC and CQA personnel to understand how material properties can influence the performance of a soil liner.

2.2.1.1 Plasticity Characteristics

The plasticity of a soil refers to the capability of a material to behave as a plastic, moldable material. Soils are said to be either plastic or non-plastic. Soils that contain clay are usually plastic whereas those that do not contain clay are usually non-plastic. If the soil is non-plastic, the soil is almost always considered unsuitable for a soil liner unless additives such as bentonite are introduced.

The plasticity characteristics of a soil are quantified by three parameters: liquid limit, plastic limit, and plasticity index. These terms are defined as follows:

- Liquid Limit (LL): The water content corresponding to the arbitrary limit between the liquid and plastic states of consistency of a soil.

- Plastic Limit (PL): The water content corresponding to the arbitrary limit between the plastic and solid states of consistency of a soil.

- Plasticity Index (PI): The numerical difference between liquid and plastic limits, i.e., LL - PL.

The liquid limit and plastic limit are measured using ASTM D-4318.

Experience has shown that if the soil has extremely low plasticity, the soil will possess insufficient clay to develop low hydraulic conductivity when the soil is compacted. Also, soils that have very low PI's tend to grade into non-plastic soils in some locations. The question of how low the PI can be before the soil is not sufficiently plastic is impossible to answer universally. Daniel (1990) recommends that the soil have a PI $\geq$ 10% but notes that some soils with PI's as low as 7% have been used successfully to build soil liners with extremely low in situ hydraulic conductivity (Albrecht and Cartwright, 1989). Benson et al. (1992) compiled a data base from CQA documents and related the hydraulic conductivity measured in the laboratory on small, "undisturbed" samples of field-compacted soil to various soil characteristics. The observed relationship between hydraulic conductivity and plasticity index is shown in Fig. 2.8. The data base reflects a broad range of construction conditions, soil materials, and CQA procedures. It is clear from the data base that many soils with PI's as low as approximately 10% can be compacted to achieve a hydraulic conductivity $\leq 1 \times 10^{-7}$ cm/s.

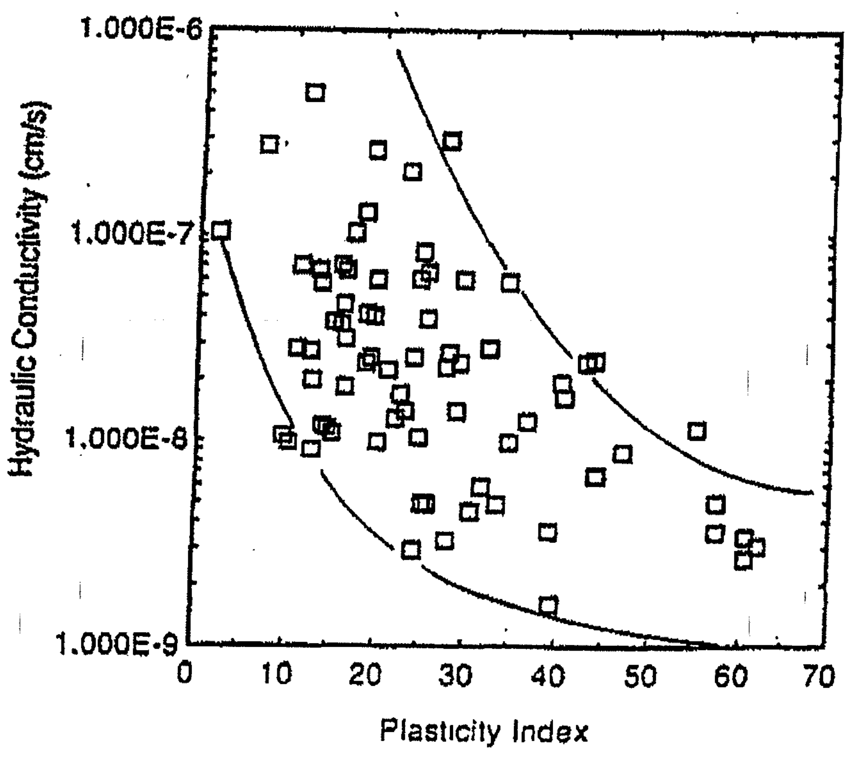


Figure 2.8 - Relationship between Hydraulic Conductivity and Plasticity Index (Benson et al., 1992)

Soils with high plasticity index (>30% to 40%) tend to form hard clods when dried and sticky clods when wet. Highly plastic soils also tend to shrink and swell when wetted or dried. With highly plastic soils, CQC and CQA personnel should be particularly watchful for proper processing of clods, effective remolding of clods during compaction, and protection from desiccation.

2.2.1.2 Percentage Fines

Some earthwork specifications place a minimum requirement on the percentage of fines in the soil liner material. *Fines* are defined as the fraction of soil that passes through the openings of the No. 200 sieve (opening size = 0.075 mm). Soils with inadequate fines typically have too little silt- and clay-sized material to produce suitably low hydraulic conductivity. Daniel (1990) recommends that the soil liner materials contain at least 30% fines. Data from Benson et al. (1992), shown in Fig. 2.9, suggest that a minimum of 50% fines might be an appropriate requirement for many soils. Field inspectors should check the soil to make sure the percentage of fines meets or exceeds the minimum stated in the construction specifications and should be particularly watchful for soils with less than 50% fines.

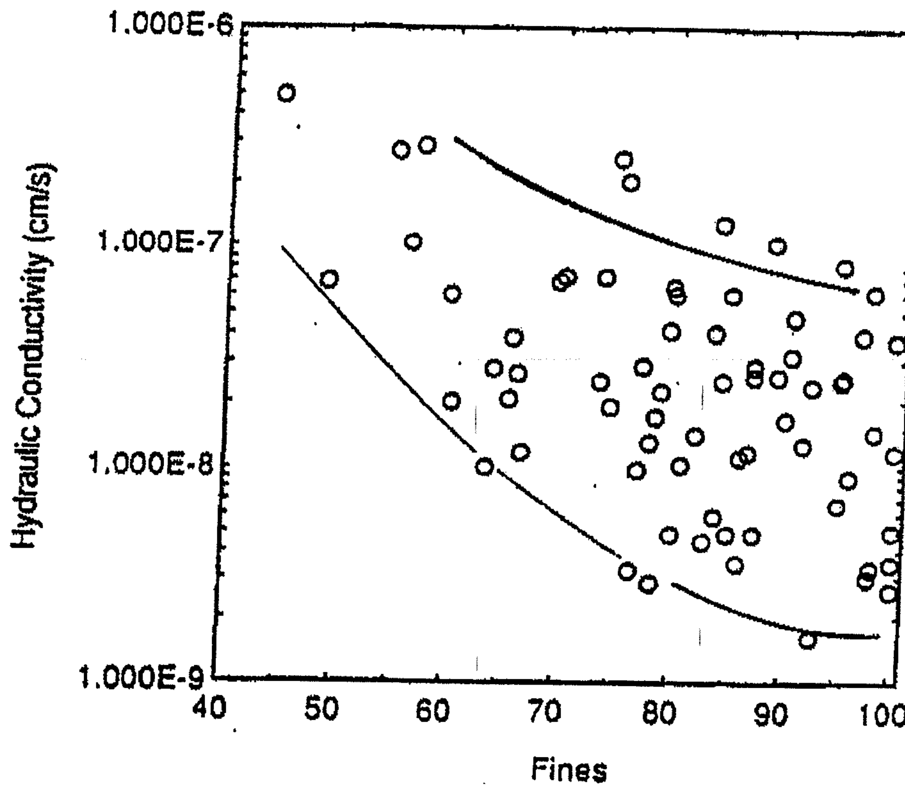


Figure 2.9 - Relationship between Hydraulic Conductivity and Percent Fines (Benson et al., 1992)

2.2.1.3 Percentage Gravel

Gravel is herein defined as particles that will not pass through the openings of a No. 4 sieve (opening size = 4.76 mm). Gravel itself has a high hydraulic conductivity. However, a relatively large percentage (up to about 50%) of gravel can be uniformly mixed with a soil liner material without significantly increasing the hydraulic conductivity of the material (Fig. 2.10). The hydraulic conductivity of mixtures of gravel and clayey soil is low because the clayey soil fills the voids between the gravel particles. The critical observation for CQA inspectors to make is for possible segregation of gravel into pockets that do not contain sufficient soil to plug the voids between the gravel particles. The uniformity with which the gravel is mixed with the soil is more important than the gravel content itself for soils with no more than 50% gravel by weight. Gravel also may possess the capability of puncturing geosynthetic materials -- the maximum size and the angularity of the gravel are very important for the layer of soil that will serve as a foundation layer for a geomembrane.

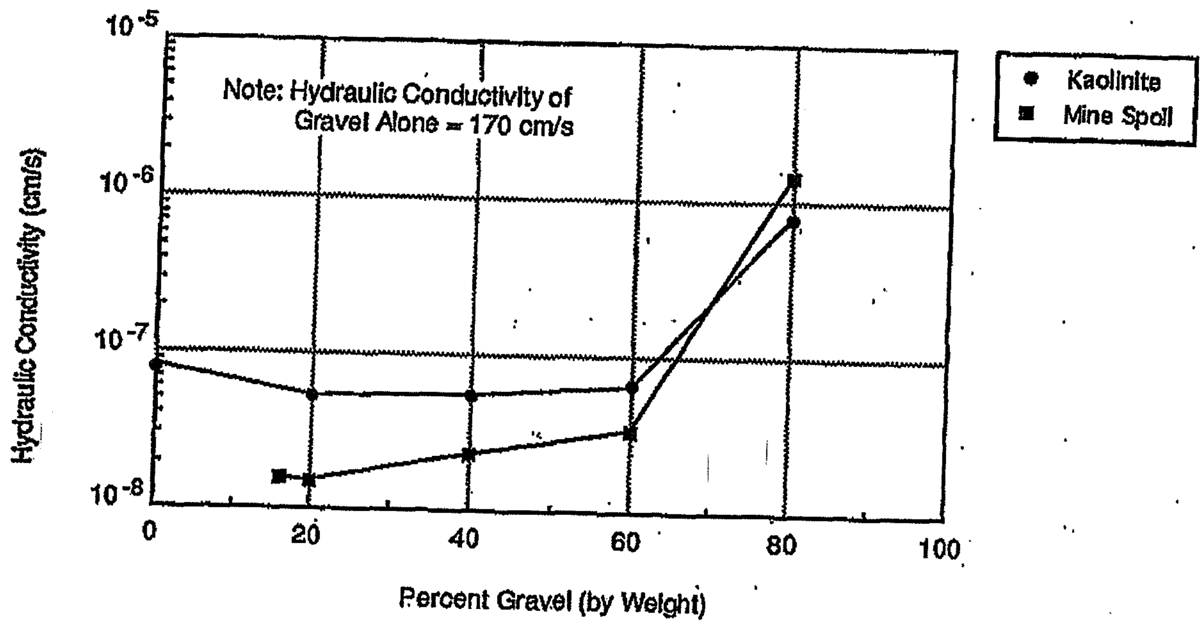


Figure 2.10 - Relationship between Hydraulic Conductivity and Percentage Gravel Added to Two Clayey Soils (after Shelley and Daniel, 1993).

2.2.1.4 Maximum Particle Size

The maximum particle size is important because: (1) cobbles or large stones can interfere with compaction, and (2) if a geomembrane is placed on top of the compacted soil liner, oversized particles can damage the geomembrane. Construction specifications may stipulate the maximum allowable particle size, which is usually between 25 and 50 mm (1 to 2 in.) for compaction considerations but which may be much less for protection against puncture of an adjacent geomembrane. If a geomembrane is to be placed on the soil liner, only the upper lift of the soil liner is relevant in terms of protection against puncture. Construction specifications may place one set of restrictions on all lifts of soil and place more stringent requirements on the upper lift to protect the geomembrane from puncture. Sieve analyses on small samples will not usually lead to detection of an occasional piece of oversized material. Observations by attentive CQC and CQA personnel are the most effective way to ensure that oversized materials have been removed. Oversized materials are particularly critical for the top lift of a soil liner if a geomembrane is to be placed on the soil liner to form a composite geomembrane/soil liner.

2.2.1.5 Clay Content and Activity

The clay content of the soil may be defined in several ways but it is usually considered to be the percentage of soil that has an equivalent particle diameter smaller than 0.005 or 0.002 mm, with 0.002 mm being the much more common definition. The clay content is measured by sedimentation analysis (ASTM D-422). Some construction specifications specify a minimum clay content but many do not.

A parameter that is sometimes useful is the activity, A, of the soil, which is defined as the plasticity index (expressed as a percentage) divided by the percentage of clay (< 0.002 mm) in the soil. A high activity (> 1) indicates that expandable clay minerals such as montmorillonite are present. Lambe and Whitman (1969) report that the activities of kaolinite, illite, and montmorillonite (three common clay minerals) are 0.38, 0.9, and 7.2, respectively. Activities for naturally occurring clay liner materials, which contain a mix of minerals, is frequently in the range of $0.5 \leq A \leq 1$.

Benson et al. (1992) related hydraulic conductivity to clay content (defined as particles < 0.002 mm) and reported the correlation shown in Fig. 2.11. The data suggest that soils must have at least 10% to 20% clay in order to be capable of being compacted to a hydraulic conductivity $\leq 1 \times 10^{-7}$ cm/s. However, Benson et al. (1992) also found that clay content correlated closely with plasticity index (Fig. 2.12). Soils with PI >10% will generally contain at least 10% to 20% clay.

It is recommended that construction specification writers and regulation drafters indirectly account for clay content by requiring the soil to have an adequate percentage of fines and a suitably large plasticity index -- by necessity the soil will have an adequate amount of clay.

2.2.1.6 Clod Size

The term *clod* refers to chunks of cohesive soil. The maximum size of clods may be specified in the construction specifications. Clod size is very important for dry, hard, clay-rich soils (Benson and Daniel, 1990). These materials generally must be broken down into small clods in order to be properly hydrated, remolded, and compacted. Clod size is less important for wet soils -- soft, wet clods can usually be remolded into a homogeneous, low-hydraulic-conductivity mass with a reasonable compactive effort.

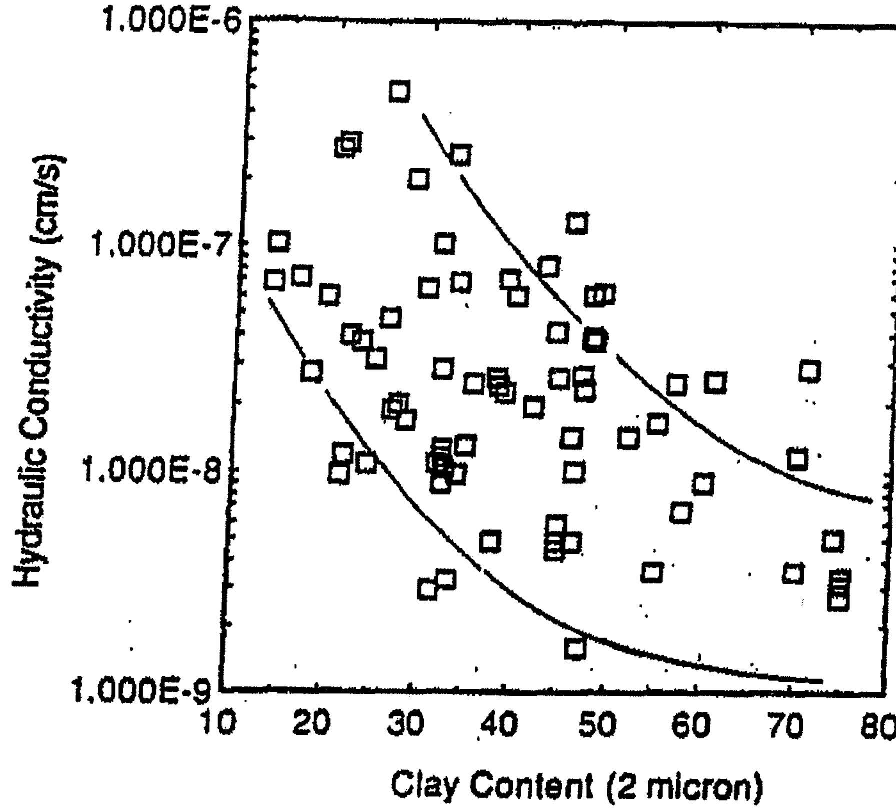


Figure 2.11 - Relationship between Hydraulic Conductivity and Clay Content (Benson et al., 1992)

No standard method is available to determine clod size. Inspectors should observe the soil liner material and occasionally determine the dimensions of clods by direct measurement with a ruler to verify conformance with construction specifications.

2.2.1.7 Bentonite

Bentonite may be added to clay-deficient soils in order to fill the voids between the soil particles with bentonite and to produce a material that, when compacted, has a very low hydraulic conductivity. The effect of the addition of bentonite upon hydraulic conductivity is shown in Fig. 2.13 for one silty sand. For this particular soil, addition of 4% sodium bentonite was sufficient to lower the hydraulic conductivity to less than 1 x 10^{-7} cm/s.

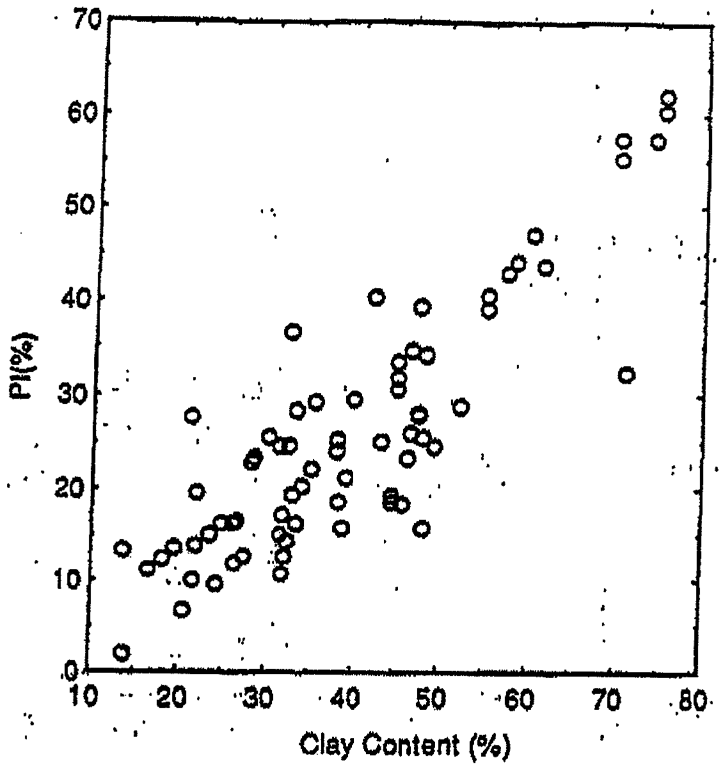


Figure 2.12 - Relationship between Clay Content and Plasticity Index (Benson et al., 1992)

The critical CQC and CQA parameters are the type of bentonite, the grade of bentonite, the grain size distribution of the processed bentonite, the amount of bentonite added to the soil, and the uniformity of mixing of the bentonite with the soil. Two types of bentonite are the primary commercial materials: sodium and calcium bentonite. Sodium bentonite has much greater water absorbency and swelling potential, but calcium bentonite may be more stable when exposed to certain chemicals. Sodium bentonite is used more frequently than calcium bentonite as a soil amendment for lining applications.

Any given type of bentonite may be available in several grades. The grade is a function of impurities in the bentonite, processing procedures, or additives. Some calcium bentonites are processed with sodium solutions to modify the bentonite to a sodium form. Some companies add polymers or other compounds to the bentonite to make the bentonite more absorbent of water or more resistant to alteration by certain chemicals.

Another variable is the gradation of the bentonite. A facet often overlooked by CQC and CQA inspectors is the grain size distribution of the processed bentonite. Bentonite can be ground to different degrees. A fine, powdered bentonite will behave differently from a coarse, granular bentonite -- if the bentonite was supposed to be finely ground but too coarse a grade was delivered, the bentonite may be unsuitable in the mixture amounts specified. Because bentonite is available in variable degrees of pulverization, a sieve analysis (ASTM D422) of the processed dry bentonite is recommended to determine the grain size distribution of the material.

The most difficult parameters to control are sometimes the amount of bentonite added to the soil and the thoroughness of mixing. Field CQC and CQA personnel should observe operational practices carefully.

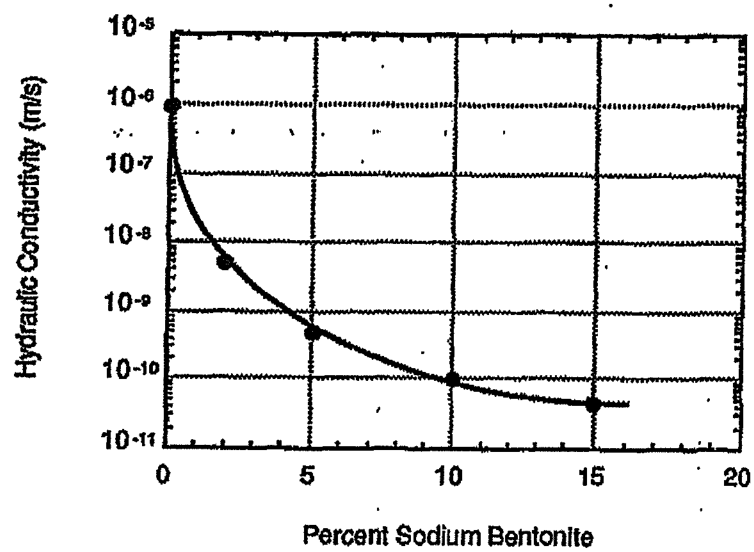


Figure 2.13 - Effect of Addition of Bentonite to Hydraulic Conductivity of Compacted Silty Sand

2.2.2 Molding Water Content

For natural soils, the degree of saturation of the soil liner material at the time of compaction is perhaps the single most important variable that controls the engineering properties of the compacted material. The typical relationship between hydraulic conductivity and molding water content is shown in Fig. 2.14. Soils compacted at water contents less than optimum (*dry of optimum*) tend to have a relatively high hydraulic conductivity; soils compacted at water contents greater than optimum (*wet of optimum*) tend to have a low hydraulic conductivity and low strength. For some soils, the water content relative to the plastic limit (which is the water content of the soil when the soil is at the boundary between being a solid and plastic material) may indicate the degree to which the soil can be compacted to yield low hydraulic conductivity. In general, if the water content is greater than the plastic limit, the soil is in a plastic state and should be capable of being remolded into a low-hydraulic-conductivity material. Soils with water contents dry of the plastic limit will exhibit very little "plasticity" and may be difficult to compact into a low-hydraulic-conductivity mass without delivering enormous compactive energy to the soil. With soil-bentonite mixes, molding water content is usually not as critical as it is for natural soils.

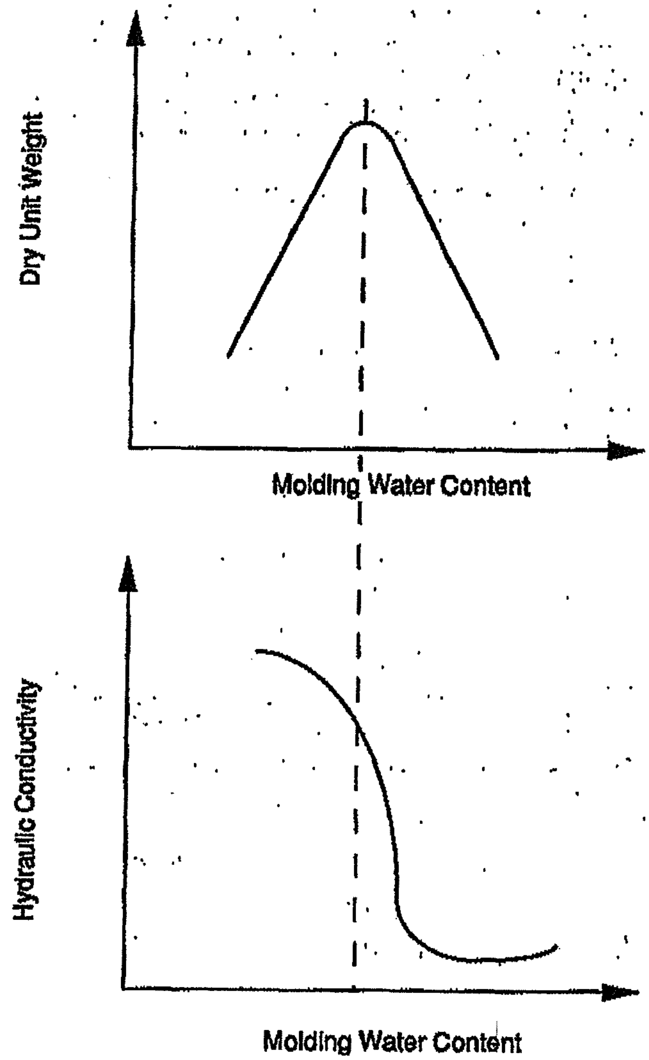


Figure 2.14 - Effect of Molding Water Content on Hydraulic Conductivity

The water content of highly plastic soils is particularly critical. A photograph of a highly plastic soil (PI = 41%) compacted 1% dry of the optimum water content of 17% is shown in Fig. 2.15. Large inter-clod voids are visible; the clods of clay were too dry and hard to be effectively remolded with the compactive effort used. A photograph of a compacted specimen of the same soil moistened to 3% wet of optimum and then compacted is shown in Fig. 2.16. At this water content, the soft soil could be remolded into a homogenous, low-hydraulic-conductivity mass.

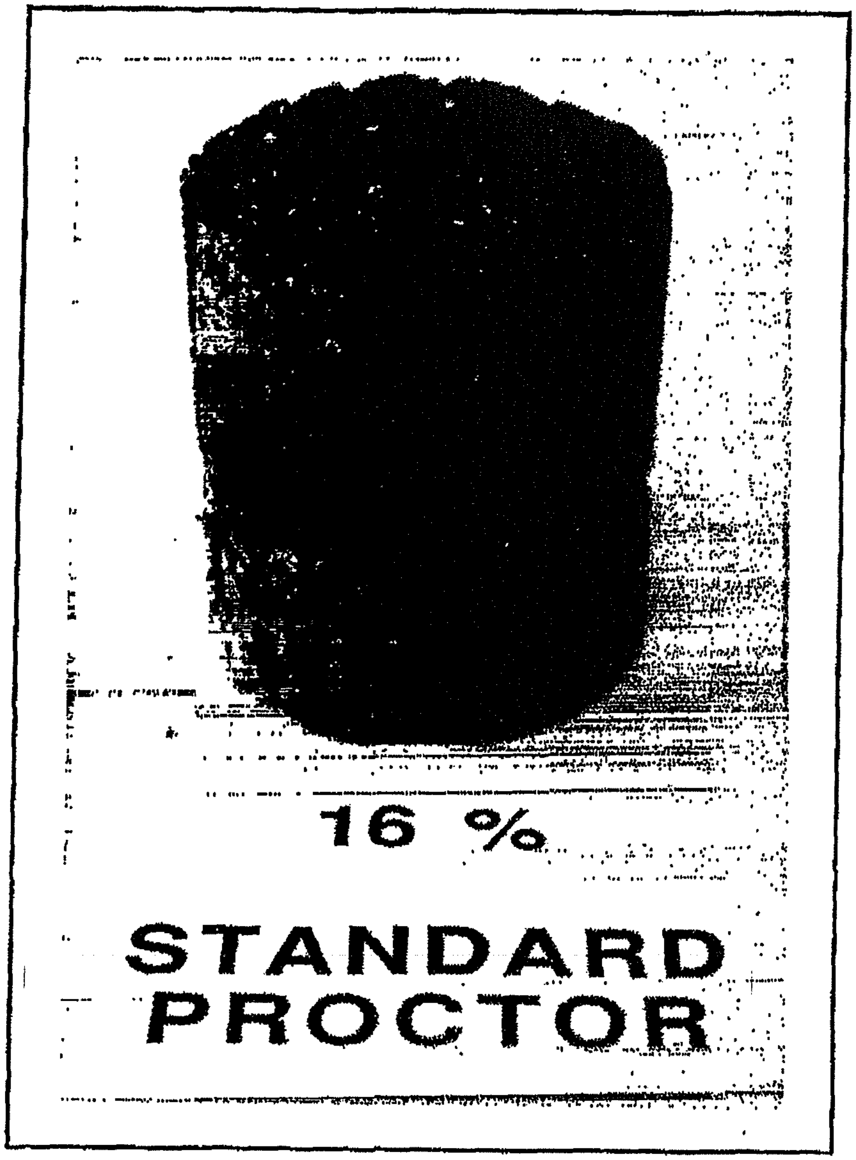


Figure 2.15 - Photograph of Highly Plastic Clay Compacted with Standard Proctor Effort at a Water Content of 16% (1% Dry of Optimum).

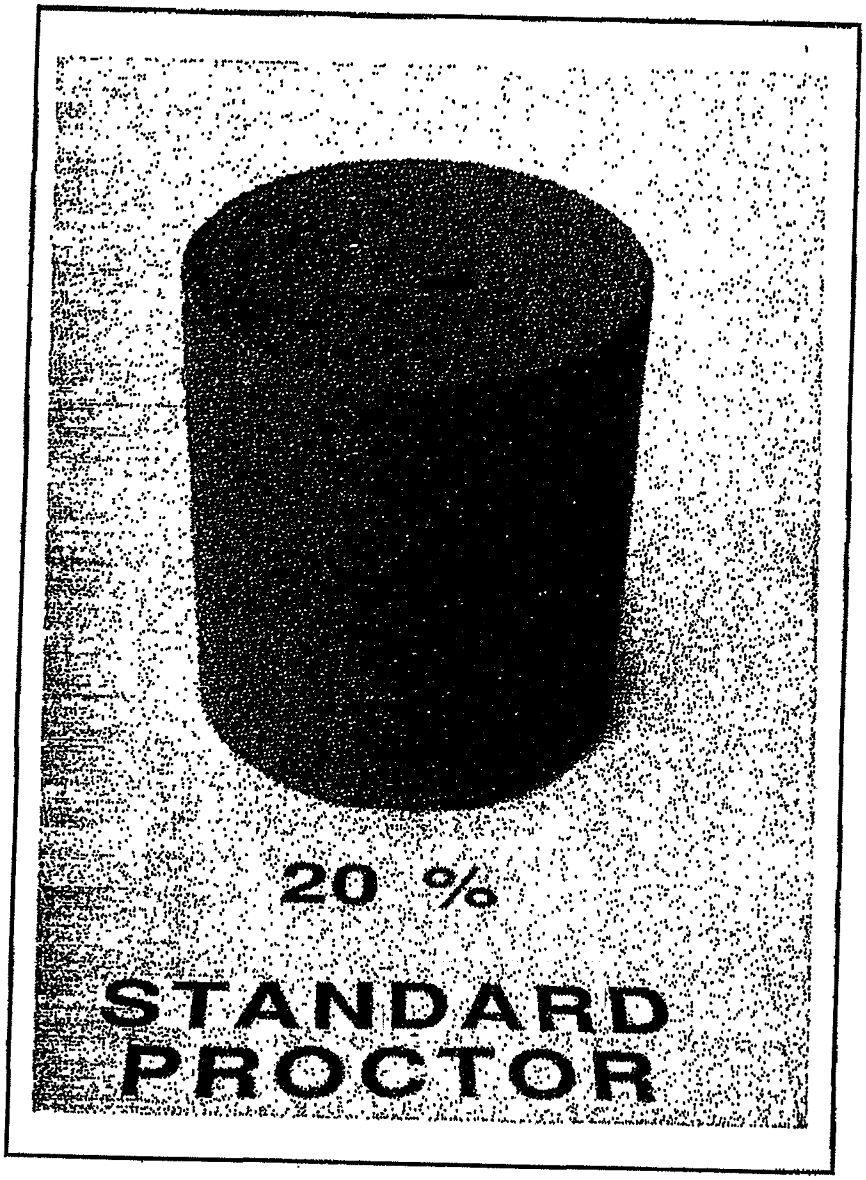


Figure 2.16 - Photograph of Highly Plastic Clay Compacted with Standard Proctor Effort at a Water Content of 20% (3% Wet of Optimum).

It is usually preferable to compact the soil wet of optimum to minimize hydraulic conductivity. However, the soil must not be placed at too high a water content. Otherwise, the shear strength may be too low, there may be great risk of desiccation cracks forming if the soil dries, and ruts may form when construction vehicles pass over the liner. It is critically important that CQC and CQA inspectors verify that the water content of the soil is within the range specified in the construction documents.

2.2.3 Type of Compaction

In the laboratory, soil can be compacted in four ways:

1. Impact Compaction: A ram is repeatedly raised and dropped to compact a lift soil into a mold (Fig. 2.17a), e.g., standard and modified Proctor.
2. Static Compaction: A piston compacts a lift of soil with a constant stress (Fig. 2.17b).
3. Kneading Compaction: A "foot" kneads the soil (Fig. 2.17c).
4. Vibratory Compaction: The soil is vibrated to densify the material (Fig. 2.17d).

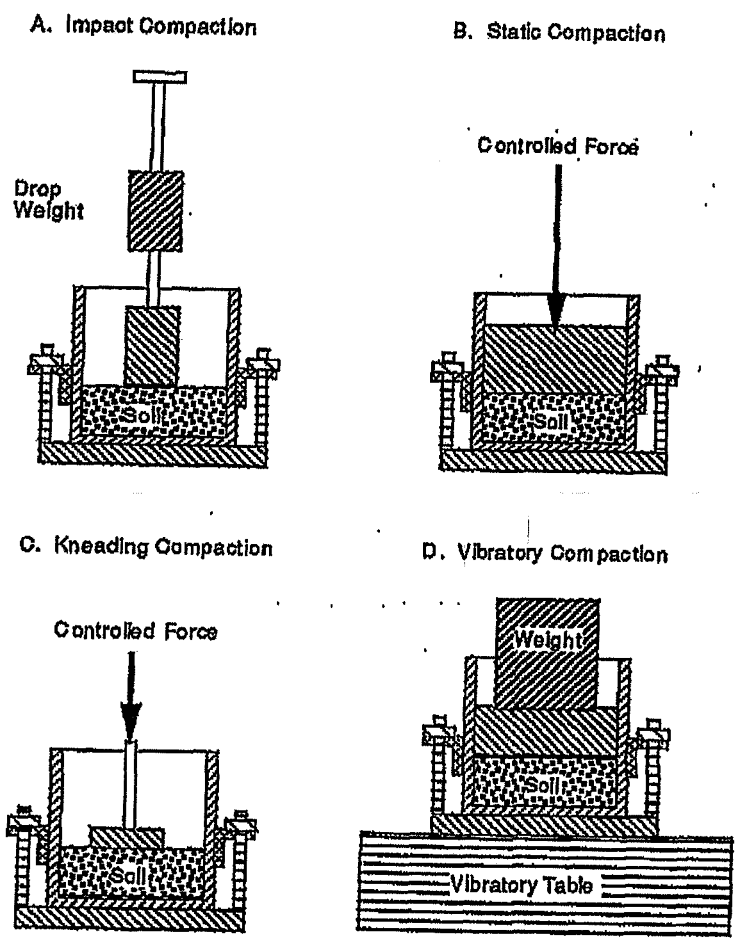


Figure 2.17 - Four Types of Laboratory Compaction Tests

Experience from the laboratory has shown that the type of compaction can affect hydraulic conductivity, e.g., as shown in Fig. 2.18. Kneading the soil helps to break down clods and remold the soil into a homogenous mass that is free of voids or large pores. Kneading of the soil is particularly beneficial for highly plastic soils. For certain bentonite-soil blends that do not form clods, kneading is not necessary. Most soil liners are constructed with "footed" rollers. The "feet" on the roller penetrate into a loose lift of soil and knead the soil with repeated passages of the roller. The dimensions of the feet on rollers vary considerably. Footed rollers with short feet (≈ 75 mm or 3 in.) are called "pad foot" rollers; the feet are said to be "partly penetrating" because the foot is too short to penetrate fully a typical loose lift of soil. Footed rollers with long feet (≈ 200 mm or 8 in.) are often called "sheepsfoot" rollers; the feet fully penetrate a typical loose lift. Figure 2.19 contrasts rollers with partly and fully penetrating feet.

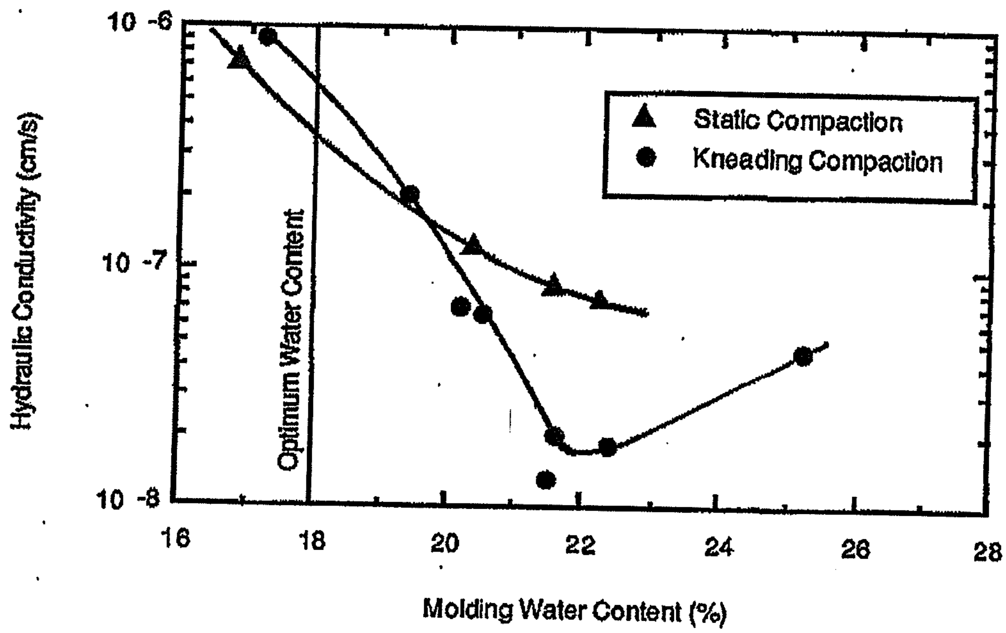


Figure 2.18 - Effect of Type of Compaction on Hydraulic Conductivity (from Mitchell et al., 1965)

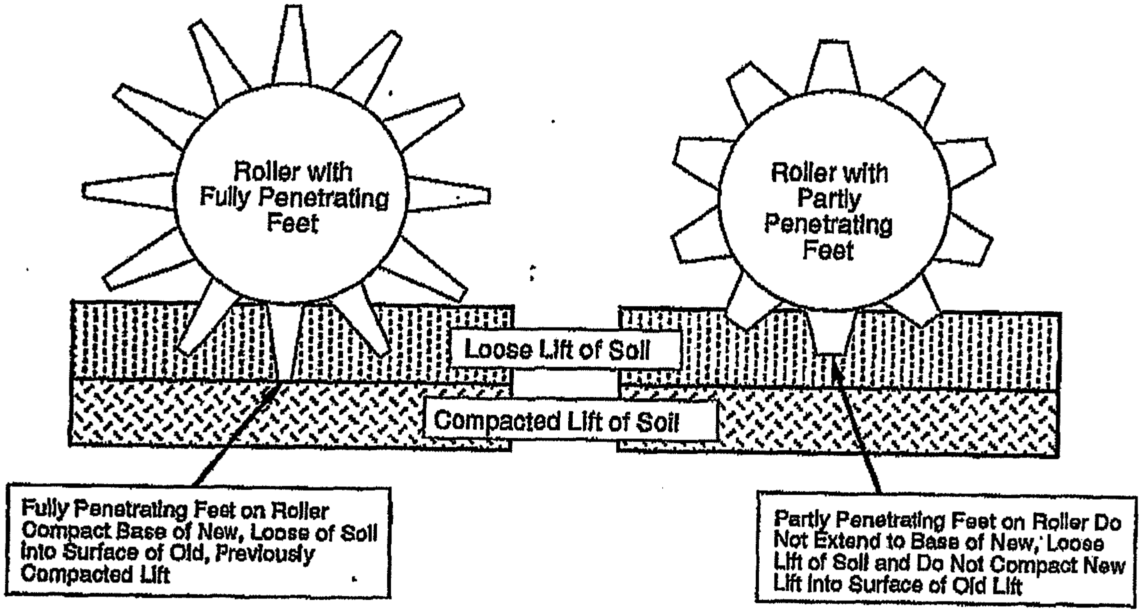


Figure 2.19 - Footed Rollers with Partly and Fully Penetrating Feet

Some construction specifications place limitations on the type of roller that can be used to compact a soil liner. Personnel performing CQC and CQA should be watchful of the type of roller to make sure it conforms to construction specifications. It is particularly important to use a roller with fully penetrating feet if such a roller is required; use of a non-footed roller or pad foot roller would result in less kneading of the soil.

2.2.4 Energy of Compaction

The energy used to compact soil can have an important influence on hydraulic conductivity. The data shown in Fig. 2.20 show that increasing the compactive effort produces soil that has a greater dry unit weight and lower hydraulic conductivity. It is important that the soil be compacted with adequate energy if low hydraulic conductivity is to be achieved.

In the field, compactive energy is controlled by:

1. The weight of the roller and the way the weight is distributed (greater weight produces more compactive energy).

2. The thickness of a loose lift (thicker lifts produce less compactive energy per unit volume of soil).

3. The number of passes of the compactor (more passes produces more compactive energy).

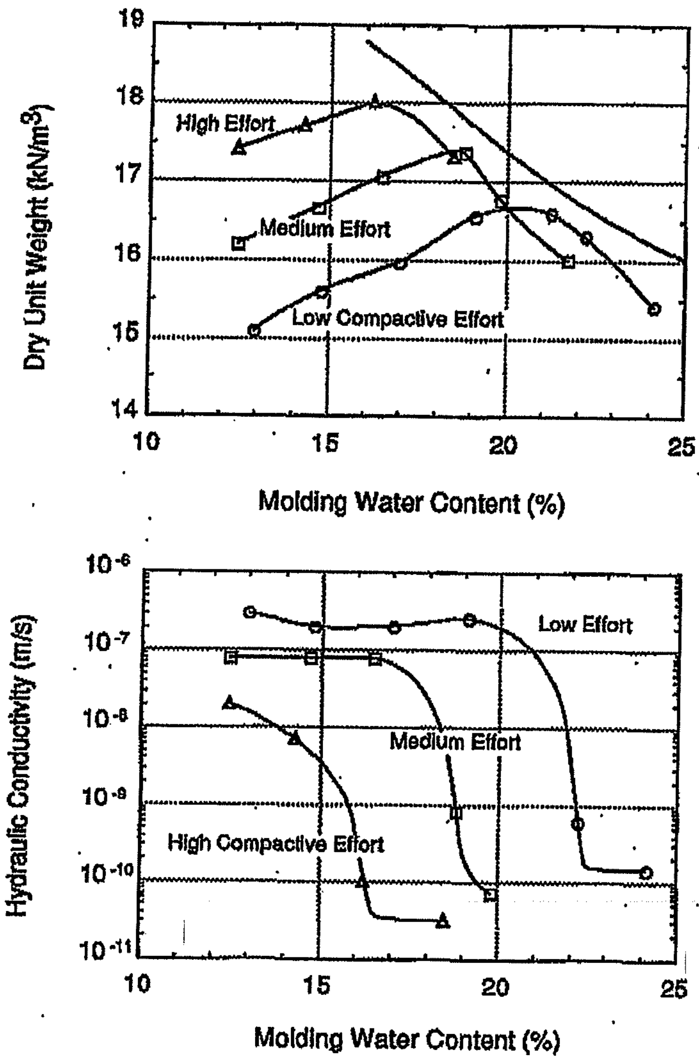


Figure 2.20 - Effect of Compactive Energy on Hydraulic Conductivity (after Mitchell et al., 1965)

Many engineers and technicians assume that percent compaction is a good measure of compactive energy. Indeed, for soils near optimum water content or dry of optimum, percent compaction is a good indicator of compactive energy: if the percent compaction is low, then the compactive energy was almost certainly low. However, for soil compacted wet of optimum, percent compaction is not a particularly good indicator of compactive energy. This is illustrated by the curves in Fig. 2.21. The same soil is compacted with Compactive Energy A and Energy B (Energy B > Energy A) to develop the compaction curves shown in Fig. 2.21. Next, two specimens are compacted to the same water content ($w_A = w_B$). The dry unit weights are practically identical ($\gamma_{d,A} \approx \gamma_{d,B}$) despite the fact that the energies of compaction were different. Further, the hydraulic conductivity (k) of the specimen compacted with the larger energy (Energy B) has a lower hydraulic conductivity than the specimen compacted with Energy A despite the fact that $\gamma_{d,A} \approx \gamma_{d,B}$. The percent compaction for the two compacted specimens is computed as follows:

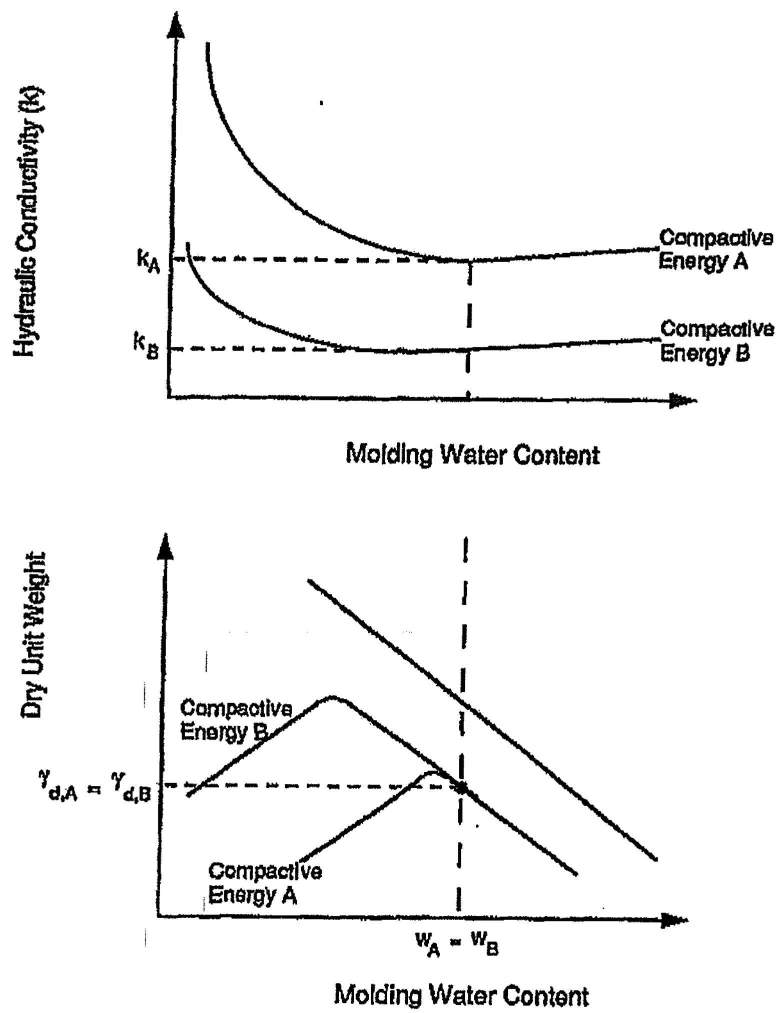


Figure 2.21 - Illustration of Why Dry Unit Weight Is a Poor Indicator of Hydraulic Conductivity for Soil Compacted Wet of Optimum

$$P_A = \gamma_{d,A}/[\gamma_{d,max}]_A \times 100\%$$

$$P_B = \gamma_{d,B}/[\gamma_{d,max}]_B \times 100\%$$

Since $\gamma_{d,A} = \gamma_{d,B}$ but $[\gamma_{d,max}]_B > [\gamma_{d,max}]_A$, then $P_A > P_B$. Thus, based on percent compaction, since $P_A > P_B$, one might assume Soil A was compacted with greater compactive energy than Soil B. In fact, just the opposite is true. CQC and CQA personnel are strongly encouraged to monitor equipment weight, lift thickness, and number of passes (in addition to dry unit weight) to ensure that appropriate compactive energy is delivered to the soil. Some CQC and CQA inspectors have failed to realize that footed rollers towed by a dozer must be filled with liquid to have the intended large weight.

Experience has shown that effective CQC and CQA for soil liners can be accomplished using the line of optimums as a reference. The "line of optimums" is the locus of (w_{opt}, $\gamma_{d,max}$) points for compaction curves developed on the same soil with different compactive energies (Fig. 2.22). The greater the percentage of actual (w,γ_d) points that lie above the line of optimums the better the overall quality of construction (Benson and Boutwell, 1992). Inspectors are encouraged to monitor the percentage of field-measured (w,γ_d) points that lie on or above the line of optimums. If the percentage is less than 80% to 90%, inspectors should carefully consider whether adequate compactive energy is being delivered to the soil (Benson and Boutwell, 1992).

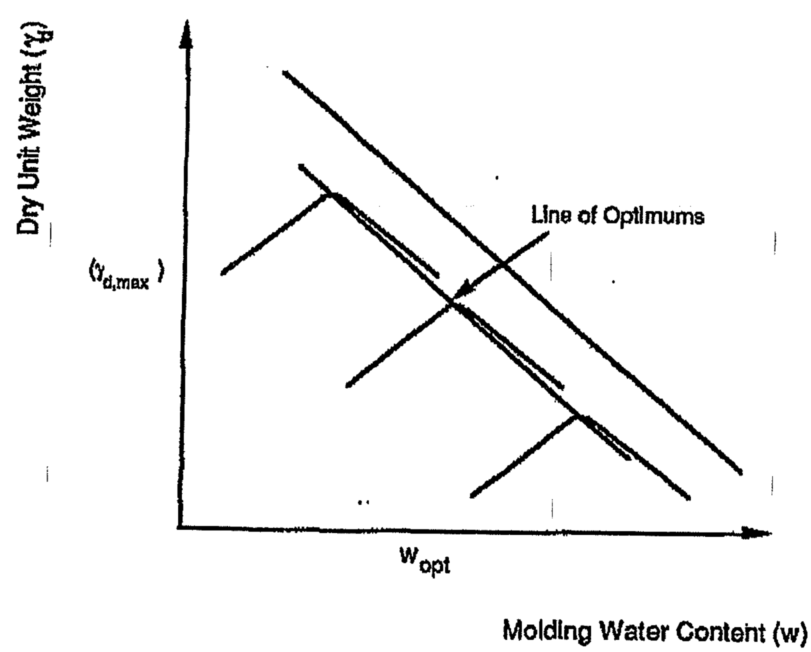


Figure 2.22 - Line of Optimums

2.2.5 Bonding of Lifts

If lifts of soil are poorly bonded, a zone of high hydraulic conductivity will develop at interfaces between lifts. Poorly bonded lift interfaces provide hydraulic connection between more permeable zones in adjacent lifts (Fig. 2.23). It is important to bond lifts together to the greatest extent possible, and to maximize hydraulic tortuosity along lift interfaces, in order to minimize the overall hydraulic conductivity.

Bonding of lifts is enhanced by:

1. Making sure the surface of a previously-compacted lift is rough before placing the new lift of soil (the previously-compacted lift is often scarified with a disc prior to placement of a new lift), which promotes bonding and increased hydraulic tortuosity along the lift interface..

2. Using a fully-penetrating footed roller (the feet pack the base of the new lift into the surface of the previously-compacted lift).

Inspectors should pay particular attention to requirements for scarification and the length of feet on rollers.

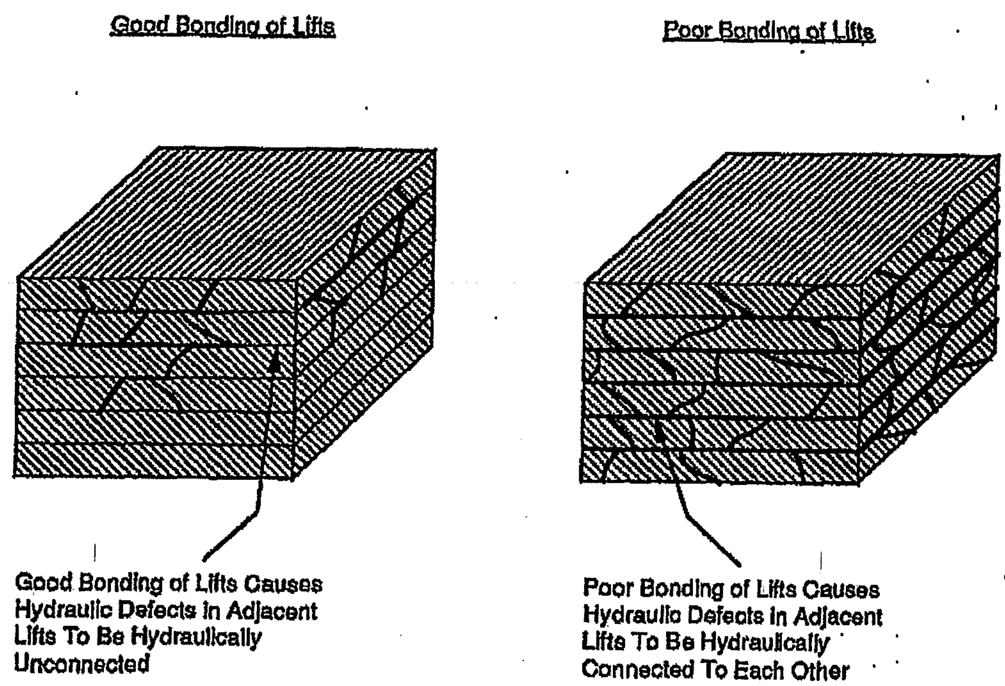


Figure 2.23 - Flow Pathways Created by Poorly Bonded Lifts

2.2.6 Protection Against Desiccation and Freezing

Clay soils shrink when they are dried and, depending on the amount of shrinkage, may crack. Cracks that extend deeper than one lift can be disastrous. Inspectors must be very careful to make sure that no significant desiccation occurs during or after construction. Water content should be measured if there are doubts.

Freezing of a soil liner will cause the hydraulic conductivity to increase. Damage caused by superficial freezing to a shallow depth is easily repaired by rerolling the surface. Deeper freezing is not so easily repaired and requires detailed investigation discussed in Section 2.9.2.3. CQC & CQA personnel should be watchful during periods when freezing temperatures are possible.

2.3 Field Measurement of Water Content and Dry Unit Weight

2.3.1 Water Content Measurement

2.3.1.1 Overnight Oven Drying (ASTM D-2216)

The standard method for determining the water content of a soil is to oven dry the soil overnight in a forced-convention oven at 110°C. This is the most fundemental and most accurate method for determining the water content of a soil. All other methods of measurement are referenced to the value of water content determined with this method.

Were it not for the fact that one has to wait overnight to determine water content with this method, undoubtedly ASTM D-2216 would be the only method of water content measurement used in the CQC and CQA processes for soil liners. However, field personnel cannot wait overnight to make decisions about continuation with the construction process.

2.3.1.2 Microwave Oven Drying (ASTM D-4643)

Soil samples can be dried in a microwave oven to obtain water contents much more quickly than can be obtained with conventional overnight oven drying. The main problem with microwave oven drying is that if the soil dries for too long in the microwave oven, the temperature of the soil will rise significantly above 110°C. If the soil is heated to a temperature greater than 110°C, one will measure a water content that is greater than the water content of the soil determined by drying at 110°C. Overheating the soil drives water out of the crystal structure of some minerals and thereby leads to too much loss of water upon oven drying.

To guard against overdrying the soil, ASTM method D-4643 requires that the soil be dried for three minutes and then weighed. The soil is then dried for an additional minute and reweighed. The process of drying for one minute and weighing the soil prevents overheating of the soil and forces the operator to cease the drying process once the weight of the soil has stabilized.

Under ideal conditions, microwave oven drying can yield water contents that are almost indistinguishable from values measured with conventional overnight oven drying. Problems that are sometimes encountered with microwave oven drying include problems in operating the oven if the soil contains significant metal and occasional problems with samples exploding from expansion of gas in the interior of the sample during microwave oven drying. Because errors can occasionally arise with microwave oven drying, the water content determined with microwave oven drying should be periodically checked with the value determined by conventional over-night oven drying (ASTM D-2216).

2.3.1.3 Direct Heating (ASTM D-4959)

Direct heating of the soil was common practice up until about two decades ago. To dry a soil with direct heating, one typically places a mass of soil into a metallic container (such as a cooking utensil) and then heats the soil over a flame, e.g., a portable cooking stove, until the soil first appears dry. The mass of the soil plus container is then measured. Next, the soil is heated some more and then re-weighed. This process is repeated until the mass ceases to decrease significantly (i.e., to change by < 0.1% or less).

The main problem with direct heating is that if the soil is overheated during drying, the water content that is measured will be too large. Although ASTM D-4959 does not eliminate this problem, the ASTM method does warn the user not to overheat the soil. Because errors can do arise with direct heating, the water content determined with direct heating should be regularly checked with the value determined by conventional over-night oven drying (ASTM D-2216).

2.3.1.4 Calcium Carbide Gas Pressure Tester (ASTM D-4944)

A known mass of moist soil is placed in a testing device and calcium carbide is introduced. Mixing is accomplished by shaking and agitating the soil with the aid of steel balls and a shaking apparatus. A measurement is made of the gas pressure produced. Water content is determined from a calibration curve. Because errors can occasionally arise with gas pressure testing, the water content determined with gas pressure testing should be periodically checked with the value determined by conventional over-night oven drying (ASTM D-2216).

2.3.1.5 Nuclear Method (ASTM D-3017)

The most widely used method of measuring the water content of compacted soil is the nuclear method. Measurement of water content with a nuclear device involves the moderation or thermalization of neutrons provided by a source of fast neutrons. Fast neutrons are neutrons with an energy of approximately 5 MeV. The radioactive source of fast neutrons is embedded in the interior part of a nuclear water content/density device (Fig. 2.24). As the fast neutrons move into the soil, they undergo a reduction in energy every time a hydrogen atom is encountered. A series of energy reductions takes place when a neutron sequentially encounters hydrogen atoms. Finally, after an average of nineteen collisions with hydrogen atoms, a neutron ceases to lose further energy and is said to be a "thermal" neutron with an energy of approximately 0.025 MeV. A detector in the nuclear device senses the number of thermal neutrons that are encountered. The number of thermal neutrons that are encountered over a given period of time is a function of the number of fast neutrons that are emitted from the source and the density of hydrogen atoms in the soil located immediately below the nuclear device. Through appropriate calibration, and with the assumption that the only source of hydrogen in the soil is water, the nuclear device provides a measure of the water content of the soil over an average depth of about 200 mm (8 in.).

There are a number of potential sources of error with the nuclear water content measuring device. The most important potential source of error is extraneous hydrogen atoms not associated with water. Possible sources of hydrogen other than water include hydrocarbons, methane gas, hydrous minerals (e.g., gypsum), hydrogen-bearing minerals (e.g., kaolinite, illite, and montmorillonite), and organic matter in the soil. Under extremely unfavorable conditions the nuclear device can yield water content measurements that are as much as ten percentage points in error (almost always on the high side). Under favorable conditions, measurement error is less than one percent. The nuclear device should be calibrated for site specific soils and changing conditions within a given site.

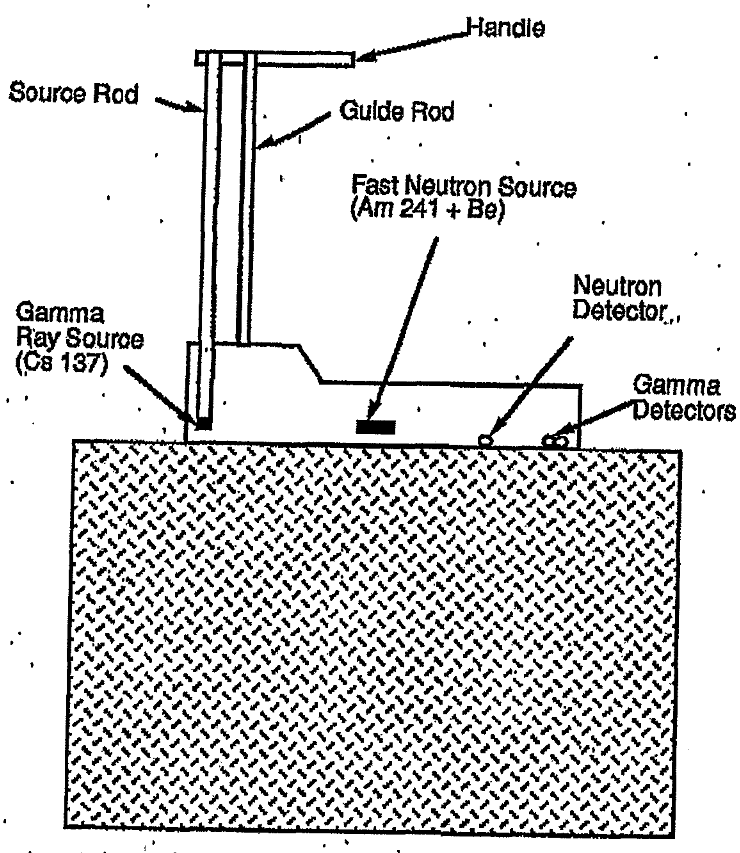


Figure 2.24 - Schematic Diagram of Nuclear Water Content - Density Device

Another potential source of error is the presence of individuals, equipment, or trenches located within one meter of the device (all of which can cause an error). The device must be warmed up for an adequate period of time or the readings may be incorrect. If the surface of the soil is improperly prepared and the device is not sealed properly against a smooth surface, erroneous measurements can result. If the standard count, which is a measure of the intensity of radiation from the source, has not been taken recently an erroneous reading may result. Finally, many nuclear devices allow the user to input a moisture adjustment factor to correct the water content reading by a fixed amount. If the wrong moisture adjustment factor is stored in the device's computer, the reported water content will be in error.

It is very important that the CQC and CQA personnel be well versed in the proper use of nuclear water content measurement devices. There are many opportunities for error if personnel are not properly trained or do not correctly use the equipment. As indicated later, the nuclear device should be checked with other types of equipment to ensure that site-specific variables are not influencing test results. Nuclear equipment may be checked against other nuclear devices (particularly new devices or recently calibrated devices) to minimize potential for errors.

2.3.2 Unit Weight

2.3.2.1 Sand Cone (ASTM D-1556)

The sand cone is a device for determining the volume of a hole that has been excavated into soil. The idea is to determine the weight of sand required to fill a hole of unknown volume. Through calibration, the volume of sand that fills the hole can be determined from the weight of sand needed to fill the hole. A schematic diagram of the sand cone is shown in Fig. 2.25.

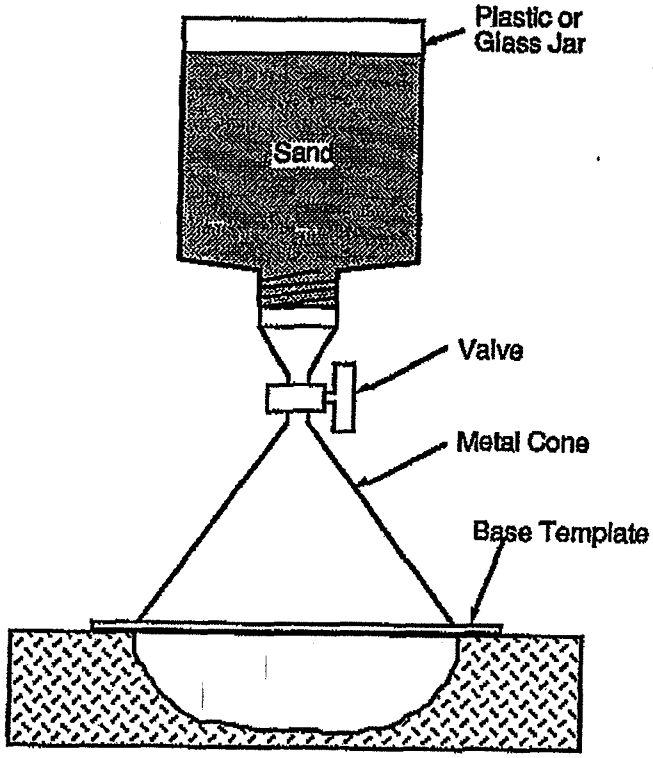


Figure 2.25 - Sand Cone Device

The sand cone is used as follows. First, a template is placed on the ground surface. A circle is scribed along the inside of the hole in the template. The template is removed and soil is excavated from within the area marked by the scribed circle. The soil that is excavated is weighed to determine the total weight (W) of the soil excavated. The excavated soil is oven dried (e.g., with a microwave oven) to determine the water content of the soil. The bottle in a sand cone device is filled with sand and the full bottle is weighed. The template is placed over the hole and the sand cone device is placed on top of the template. A valve on the sand cone device is opened, which allows sand to rain down through the inverted funnel of the device and inside the excavated hole.

When the hole and funnel are filled with sand, the valve is closed and the bottle containing sand is weighed. The difference in weight before and after the hole is dug is calculated. Through calibration, the weight of sand needed to fill the funnel is subtracted, and the volume of the hole is computed from the weight of sand that filled the hole. The total unit weight is calculated by dividing the weight of soil excavated by the computed volume of the excavated hole. The dry unit weight is then calculated from Eq. 2.1.

The sand cone device provides a reliable technique for determining the dry unit weight of the soil. The primary sources of error are improper calibration of the device, excavation of an uneven hole that has sharp edges or overhangs that can produce voids in the sand-filled hole, variations in the sand, excessively infrequent calibrations, contamination of the sand by soil particles if the sand is reused, and vibration as from equipment operating close to the sand cone.

2.3.2.2 Rubber Balloon (ASTM D-2167)

The rubber balloon is similar to the sand cone except that water is used to fill the excavated hole rather than sand. A rubber balloon device is sketched in Fig. 2.26. As with the sand cone test, the test is performed with the device located on the template over the leveled soil. Then a hole is excavated into the soil and the density measuring device is again placed on top of a template at the ground surface. Water inside the rubber balloon device is pressurized with air to force the water into the excavated hole. A thin membrane (balloon) prevents the water from entering the soil. The pressure in the water forces the balloon to conform to the shape of the excavated hole. A graduated scale on the rubber balloon device enables one to determine the volume of water required to fill the hole. The total unit weight is calculated by dividing the known weight of soil excavated from the hole by the volume of water required to fill the hole with the rubber balloon device. The dry unit weight is computed from Eq. 2.1.

The primary sources of error with the rubber balloon device are improper excavation of the hole (leaving small zones that cannot be filled by the pressurized balloon), excessive pressure that causes local deformation of the adjacent soil, rupture of the balloon, and carelessness in operating the device (e.g., not applying enough pressure to force the balloon to fill the hole completely).

2.3.2.3 Drive Cylinder (ASTM D-2937)

A drive cylinder is sketched in Fig. 2.27. A drop weight is used to drive a thin-walled tube sampler into the soil. The sampler is removed from the soil and the soil sample is trimmed flush to the bottom and top of the sampling tube. The soil-filled tube is weighed and the known weight of the sampling tube itself is subtracted to determine the gross weight of the soil sample. The dimensions of the sample are measured to enable calculation of volume. The unit weight is calculated by dividing the known weight by the known volume of the sample. The sample is oven dried (e.g., in a microwave oven) to determine water content. The dry unit weight is computed from Eq. 2.1.

The primary problems with the drive cylinder are sampling disturbance caused by rocks or stones in the soil, densification of the soil caused by compression resulting from driving of the tube into the soil, and nonuniform driving of the tube into the soil. The drive cylinder method is not recommended for stony or gravely soils. The drive cylinder method works best for relatively soft, wet clays that do not tend to densify significantly when the tube is driven into the soil and for soils that are free of gravel or stones. However, even under favorable circumstances, densification of the soil caused by driving the ring into the soil can cause an increase in total unit weight of 2 to 5 pcf (0.3 to 0.8 kN/m^3).

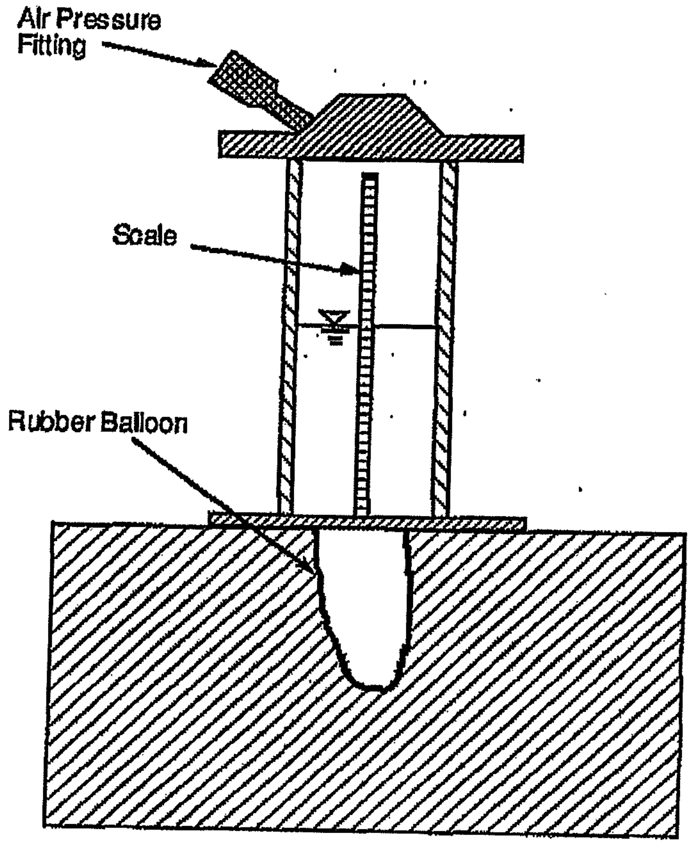


Figure 2.26 - Schematic Diagram of Rubber Balloon Device

2.3.2.4 Nuclear Method (ASTM D-2922)

Unit weight can be measured with a nuclear device operated in two ways as shown in Fig. 2.28. The most common usage is called *direct transmission* in which a source of gamma radiation is lowered down a hole made into the soil to be tested (Fig. 2.28a). Detectors located in the nuclear density device sense the intensity of gamma radiation at the ground surface. The intensity of gamma radiation detected at the surface is a function of the intensity of gamma radiation at the source and the total unit weight of the soil material. The second mode of operation of the nuclear density device is called *backscattering*. With this technique the source of gamma radiation is located at the ground surface (Fig. 2.28b). The intensity of gamma radiation detected at the surface is a function of the density of the soil as well as the radioactivity of the source. With the backscattering technique, the measurement is heavily dependent upon the density of the soil within the upper 25 to 50 mm of soil. The direct transmission method is the recommended technique for soil liners because direct transmission provides a measurement averaged over a greater depth than backscattering.

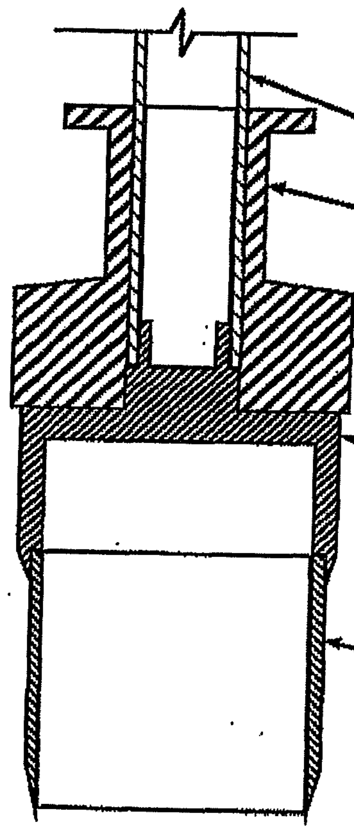
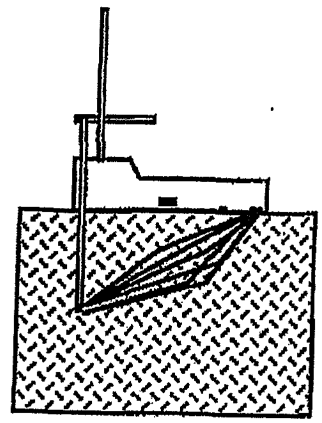


Figure 2.27 - Schematic Diagram of Drive Ring

The operation of a nuclear density device in the direct transmission mode is as follows. First, the area to be tested is smoothed, and a hole is made into the soil liner material by driving a rod (called the *drive rod*) into the soil. The diameter of the hole is approximately 25 mm (1 in.) and the depth of the hole is typically 50 mm (2 in.) greater than the depth to which the gamma radiation source will be lowered below the surface. The nuclear device is then positioned with the source rod directly over the hole in the soil liner material. The source rod is then lowered to a depth of approximately 50 mm (2 in.) above the base of the hole. The source is then pressed against the surface of the hole closest to the detector by pulling on the nuclear device and forcing the source to bear against the side of the hole closest to the detector. The intent is to have good contact between the source and soil along a direct line from source to detector. The intensity of radiation at the detector is measured for a fixed period of time, e.g., 30 or 60 s. The operator can select the period of counting. The longer the counting period, the more accurate the measurement. However, the counting period cannot be extended too much because productivity will suffer.

(A) Direct Transmission



(B) Backscattering

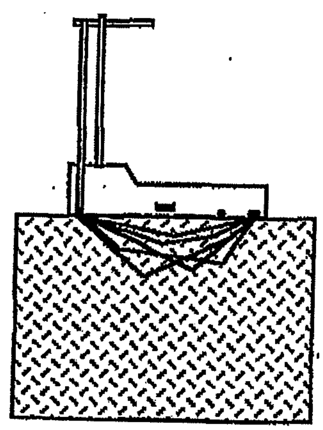


Figure 2.28 - Measurement of Density with Nuclear Device by (a) Direct Transmission and (B) Backscattering

After total unit weight has been determined, the measured water content is used to compute dry unit weight (Eq. 2.1). The potential sources of error with the nuclear device are fewer and less significant in the density-measuring mode compared to the water content measuring mode. The most serious potential source of error is improper use of the nuclear density device by the operator. One gross error that is sometimes made is to drive the source rod into the soil rather than inserting the source rod into a hole that had been made earlier with the drive rod. Improper separation of the source from the base of the hole, an inadequate period of counting, inadequate warm-up, spurious sources of gamma radiation, and inadequate calibration are other potential sources of error.

2.4 Inspection of Borrow Sources Prior to Excavation

2.4.1 Sampling for Material Tests

In order to determine the properties of the borrow soil, samples are often obtained from the potential borrow area for laboratory analysis prior to actual excavation but as part of the construction contract. Samples may be obtained in several ways. One method of sampling is to drill soil borings and recover samples of soil from the borings. This procedure can be very effective in identifying major strata and substrata within the borrow area. Small samples obtained from the borings are excellent for index property testing but often do not provide a very good indication of subtle stratigraphic changes in the borrow area. Test pits excavated into the borrow soil with a backhoe, frontend loader, or other excavation equipment can expose a large cross-section of the borrow soil. One can obtain a much better idea of the variability of soil in the potential borrow area by examining exposed cuts rather than viewing small soil samples obtained from borings.

Large bulk samples of soil are required for compaction testing in the laboratory. Small samples of soil taken with soil sampling devices do not provide a sufficient volume of soil for laboratory compaction testing. Some engineers combine samples of soil taken at different depths or from different borings to produce a composite sample of adequate volume. This technique is not recommended because a degree of mixing takes place in forming the composite laboratory test sample that would not take place in the field. Other engineers prefer to collect material from auger borings for use in performing laboratory compaction tests. This technique is likewise not recommended without careful borrow pit control because vertical mixing of material takes place during auguring in a way that would not be expected to occur in the field unless controlled vertical cuts are made. The best method for obtaining large bulk samples of material for laboratory compaction testing is to take a large sample of material from one location in the borrow source. A large, bulk sample can be taken from the wall or floor of a test pit that has been excavated into the borrow area. Alternatively, a large piece of drilling equipment such as a bucket auger can be used to obtain a large volume of soil from a discreet point in the ground.

2.4.2. Material Tests

Samples of soil must be taken for laboratory testing to ensure conformance with specifications for parameters such as percentage fines and plasticity index. The samples are sometimes taken in the borrow pit, are sometimes taken from the loose lift just prior to compaction, and are sometimes taken from both. If samples are taken from the borrow area, CQA inspectors track the approximate volumes of soil excavated and sample at the frequency prescribed in the CQA plan. Sometimes borrow-source testing is performed prior to issuing of a contract to purchase the borrow material. A CQA program cannot be implemented for work already completed. The CQA personnel will have ample opportunity to check the properties of soil materials later during excavation and placement of the soils. If the CQA personnel for a project did not observe borrow soil testing, the CQA personnel should review the results of borrow soil testing to ensure that the required tests have been performed. Additional testing of the borrow material may be required during excavation of the material.

The material tests that are normally performed on borrow soil are water content, Atterberg limits, particle size distribution, compaction curve, and hydraulic conductivity (Table 2.2). Each of these tests is discussed below.

Table 2.2 - Materials Tests

Parameter	ASTM Test Method	Title of ASTM Test
Water Content	D-2216	Laboratory Determination of Water (Moisture) Content of Soil and Rock
	D-4643	Determination of Water (Moisture) Content of Soil by the Microwave Oven Method
	D-4944	Field determination of Water (Moisture) Content of Soil by the Calcium Carbide Gas Pressure Tester Method
	D-4959	Determination of Water (Moisture) Content by Direct Heating Method
Liquid Limit, Plastic Limit, & Plasticity Index	D-4318	Liquid Limit, Plastic Limit, and Plasticity Index of Soils
Particle Size Distribution	D-422	Particle Size Analysis of Soil
Compaction Curve	D-698	Moisture-Density Relations for Soils and Soil-Aggregate Mixtures Using 5.5-lb. (2.48-kg) Rammer and 12-in. (305-mm) Drop
	D-1557	Moisture-Density Relations for Soils and Soil-Aggregate Mixtures Using 10-lb. (4.54-kg) Rammer and 18-in. (457-mm) Drop
Hydraulic Conductivity	D-5084	Measurement of Hydraulic Conductivity of Saturated Porous Materials Using A Flexible Wall Permeameter

2.4.2.1 Water Content

It is important to know the water content of the borrow soils so that the need for wetting or drying the soil prior to compaction can be identified. The water content of the borrow soil is normally measured following the procedures outlined in ASTM D-2216 if one can wait overnight for results. If not, other test methods described in Section 2.3.1 and listed in Table 2.2 can be used to produce results faster.

2.4.2.2 Atterberg Limits

Construction specifications for compacted soil liners often require a minimum value for the liquid limit and/or plasticity index of the soil. These parameters are measured in the laboratory with the procedures outlined in ASTM D-4318.

2.4.2.3 Particle Size Distribution

Construction specifications for soil liners often place limits on the minimum percentage of fines, the maximum percentage of gravel, and in some cases the minimum percentage of clay. Particle size analysis is performed following the procedures in ASTM D-422. Normally the requirements for the soil material are explicitly stated in the construction specifications. An experienced inspector can often judge the percentage of fine material and the percentage of sand or gravel in the soil. However, compliance with specifications is best documented by laboratory testing.

2.4.2.4 Compaction Curve

Compaction curves are developed utilizing the method of laboratory compaction testing required in the construction specifications. Standard compaction (ASTM D-698) and modified compaction (ASTM D-1557) are two common methods of laboratory compaction specified for soil liners. However, other compaction methods (particularly those unique to state highway or transportation departments) are sometimes specified.

Great care should be taken to follow the procedures for soil preparation outlined in the relevant test method. In particular, the drying of a cohesive material can change the Atterberg limits as well as the compaction characteristics of the soil. If the test procedure recommends that the soil not be dried, the soil should not be dried. Also, care must be taken when sieving the soil not to remove clods of cohesive material. Rather, clods of soil retained on a sieve should be broken apart by hand if necessary to cause them to pass through the openings of the sieve. Sieves should only be used to remove stones or other large pieces of material following ASTM procedures.

2.4.2.5 Hydraulic Conductivity

The hydraulic conductivity of compacted samples of borrow material may be measured periodically to verify that the soil liner material can be compacted to achieve the required low hydraulic conductivity. Several methods of laboratory permeation are available, and others are under development. ASTM D-5084 is the only ASTM procedure currently available. Care should be taken not to apply excessive effective confining stress to test specimens. If no value is specified in the CQA plan, a maximum effective stress of 35 kPa (5 psi) is recommended for both liner and cover systems.

Care should be taken to prepare specimens for hydraulic conductivity testing properly. In addition to water content and dry unit weight, the method of compaction and the compactive energy can have a significant influence on the hydraulic conductivity of laboratory-compacted soils. It is particularly important not to deliver too much compactive energy to attain a desired dry unit weight. The purpose of the hydraulic conductivity test is to verify that borrow soils can be compacted to the desired hydraulic conductivity using a reasonable compactive energy.

No ASTM compaction method exists for preparation of hydraulic conductivity test specimens. The following procedure is recommended:

1. Obtain a large, bulk sample of representative material with a mass of approximately 20 kg.

2. Develop a laboratory compaction curve using the procedure specified in the construction specifications for compaction control, e.g., ASTM D-698 or D-1557.

3. Determine the target water content (w_{target}) and dry unit weight ($\gamma_{d,target}$) for the hydraulic conductivity test specimen. The value of w_{target} is normally the lowest acceptable water content and $\gamma_{d,target}$ is normally the minimum acceptable dry unit weight (Fig. 2.29).

4. Enough soil to make several test specimens is mixed to w_{target}. The compaction procedure used in Step 2 is used to prepare a compacted specimen, except that the energy of compaction is reduced, e.g., by reducing the number of drops of the ram per lift. The dry unit weight (γ_d) is determined. If $\gamma_d \approx \gamma_{d, target}$, the compacted specimen may be used for hydraulic conductivity testing. If $\gamma_d \neq \gamma_{d,target}$, then another test specimen is prepared with a larger or smaller (as appropriate) compactive energy. Trial and error preparation of test specimens is repeated until $\gamma_d \approx \gamma_{d, target}$. The procedure is illustrated in Fig. 2.29. The actual compactive effort should be documented along with hydraulic conductivity.

5. Atterberg limits and percentage fines should be determined for each bulk sample. Water content and dry density should be reported for each compacted specimen.

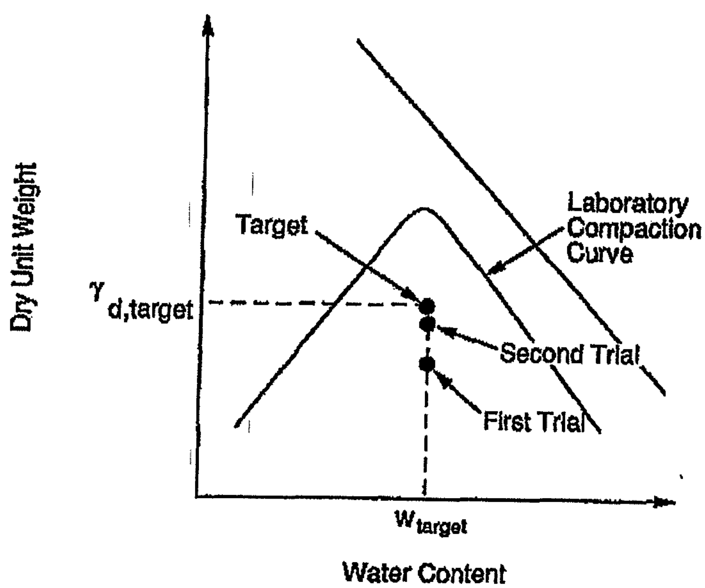


Figure 2.29 - Recommended Procedure for Preparation of a Test Specimen Using Variable (But Documented) Compactive Energy for Each Trial

2.4.2.6 Testing Frequency

The CQA plan should stipulate the frequency of testing. Recommended minimum values are shown in Table 2.3. The tests listed in Table 2.3 are normally performed prior to construction as part of the characterization of the borrow source. However, if time or circumstances do not permit characterization of the borrow source prior to construction, the samples for testing are obtained during excavation or delivery of the soil materials.

Table 2.3 - Recommended Minimum Testing Frequencies for Investigation of Borrow Source

Parameter	Frequency
Water Content	1 Test per 2000 m^3 or Each Change in Material Type
Atterberg Limits	1 Test per 5000 m^3 or Each Change in Material Type
Percentage Fines	1 Test per 5000 m^3 or Each Change in Material Type
Percent Gravel	1 Test per 5000 m^3 or Each Change in Material Type
Compaction Curve	1 Test per 5000 m^3 or Each Change in Material Type
Hydraulic Conductivity	1 Test per 10,000 m^3 or Each Change in Material Type

Note: 1 yd^3 = 0.76 m^3

2.5 Inspection during Excavation of Borrow Soil

It is strongly recommended that a qualified inspector who reports directly to the CQA engineer observe all excavation of borrow soil in the borrow pit. Often the best way to determine whether deleterious material is present in the borrow soil is to observe the excavation of the soil directly.

A key factor for inspectors to observe is the plasticity of the soil. Experienced technicians can often determine whether or not a soil has adequate plasticity by carefully examining the soil in the field. A useful practice for field identification of soils is ASTM D-2488, "Description and Identification of Soils (Visual-Manual Procedure)." The following procedure is used for identifying clayey soils.

- Dry strength: The technician selects enough soil to mold into a ball about 25 mm (1 in.) in diameter. Water is added if necessary to form three balls that each have a diameter of about 12 mm (1/2 in.). The balls are allowed to dry in the sun. The strength of the dry balls is evaluated by crushing them between the fingers. The dry strength is described with the criteria shown in Table 2.4. If the dry strength is none or low, inspectors should be alerted to the possibility that the soil lacks adequate plasticity.

- Plasticity: The soil is moistened or dried so that a test specimen can be shaped into an elongated pat and rolled by hand on a smooth surface or between the palms into a thread about 3 mm (1/8 in.) in diameter. If the sample is too wet to roll easily it should be spread into a thin layer and allowed to lose some water by evaporation. The sample threads are re-rolled repeatedly until the thread crumbles at a diameter of about 3 mm (1/8 in.). The thread will crumble at a diameter of 3 mm when the soil is near the plastic limit. The plasticity is described from the criteria shown in Table 2.5, based upon observations made during the toughness test. Non-plastic soils are usually unsuitable for use as soil liner materials without use of amendments such as bentonite.

Table 2.4 - Criteria for Describing Dry Strength (ASTM D-2488)

Description	Criteria
None	The dry specimen crumbles into powder with mere pressure of handling
Low	The dry specimen crumbles into powder with some finger pressure
Medium	The dry specimen breaks into pieces or crumbles with considerable finger pressure
High	The dry specimen cannot be broken with finger pressure. Specimen will break into pieces between thumb and a hard surface
Very High	The dry specimen cannot be broken between the thumb and a hard surface

Table 2.5 - Criteria for Describing Plasticity (ASTM D-2488)

Description	Criteria
Nonplastic	A 3 mm (1/8-in.) thread cannot be rolled at any water content
Low	The thread can barely be rolled and the lump cannot be formed when drier than the plastic limit
Medium	A thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be rerolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit
High	It takes considerable time rolling and kneading to reach the plastic limit. The thread can be rerolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit

2.6 Preprocessing of Materials

Some soil liner materials are ready to be used for final construction immediately after they are excavated from the borrow pit. However, most materials require some degree of processing prior to placement and compaction of the soil.

2.6.1 Water Content Adjustment

Soils that are too wet must first be dried. If the water content needs to be reduced by no more than about three percentage points, the soil can be dried after it has been spread in a loose lift just prior to compaction. If the water content must be reduced by more than about 3 percentage points, it is recommended that drying take place in a separate processing area. The reason for drying in a separate processing area is to allow adequate time for the soil to dry uniformly and to facilitate mixing of the material during drying. The soil to be dried is spread in a lift about 225 to 300 mm (9 to 12 in.) thick and allowed to dry. Water content is periodically measured using one or more of the methods listed in Table 2.2. The contractor's CQC personnel should check the soil periodically to determine when the soil has reached the proper water content.

The CQA inspectors should check to be sure that the soil is periodically mixed with a disc or rototiller to ensure uniform drying. The soil cannot be considered to be ready for placement and compaction unless the water is uniformly distributed; water content measurements alone do not ensure that water is uniformly distributed within the soil.

If the soil must be moistened prior to compaction, the same principles discussed above for drying apply; water content adjustment in a separate preprocessing area is recommended if the water content must be increased by more than about 3 percentage points. Inspectors should be careful to verify that water is distributed uniformly to the soil (a spreader bar on the back of a water truck is the recommended device for moistening soil uniformly), that the soil is periodically mixed with a disc or rototiller, and that adequate time has been allowed for uniform hydration of the soil. If the water content is increased by more than three percentage points, at least 24 to 48 hours would normally be required for uniform absorption of water and hydration of soil particles. The construction specifications may limit the type of water that can be used; in some cases, contaminated water, brackish water, or sea water is not allowed.

2.6.2 Removal of Oversize Particles

Oversized stones and rocks should be removed from the soil liner material. Stones and rocks interfere with compaction of the soil and may create undesirable pathways for fluid to flow through the soil liner. The construction specifications should stipulate the maximum allowable size of particles in the soil liner material.

Oversized particles can be removed with mechanical equipment (e.g., large screens) or by hand. Inspectors should examine the loose lift of soil after the contractor has removed oversized particles to verify that oversized particles are not present. Sieve analyses alone do not provide adequate assurance that oversized materials have been removed -- careful visual inspection for oversized material should be mandatory.

2.6.3 Pulverization of Clods

Some specifications for soil liners place limitations on the maximum size of chunks or clods of clay present in the soil liner material. Discs, rototillers, and road recyclers are examples of mechanical devices that will pulverize clods in a loose lift. Visual inspection of the loose lift of material is normally performed to ensure that clods of soil have been pulverized to the extent required in the construction specifications. Inspectors should be able to visually examine the entire surface of a loose lift to determine whether clods have been adequately processed. No standard method exists for determining clod size. Inspectors normally measure the dimensions of an individual clod with a ruler.

2.6.4 Homogenizing Soils

CQC and CQA are very difficult to perform for heterogeneous materials. It may be necessary to blend and homogenize soils prior to their use in constructing soil liners in order to maintain proper CQC and CQA. Soils can be blended and homogenized in a pugmill. The best way to ensure adequate mixing of materials is through visual inspection of the mixing process itself.

2.6.5 Bentonite

Bentonite is a common additive to soil liner materials that do not contain enough clay to achieve the desired low hydraulic conductivity. Inspectors must ensure that the bentonite being used for a project is in conformance with specifications (i.e., is of the proper quality and gradation) and that the bentonite is uniformly mixed with soil in the required amounts.

The parameters that are specified for the bentonite quality vary considerably from project to project. The construction specifications should stipulate the criteria to be met by the bentonite and the relevant test methods. The quality of bentonite is usually measured with some type of measurement of water adsorption ability of the clay. Direct measurement of water adsorption can be accomplished using the plate water adsorption test (ASTM E-946). This test is used primarily in the taconite iron ore industry to determine the effectiveness of bentonite, which is used as a binder during the pelletizing process to soak up excess water in the ore. Brown (1992) reports that thousands of plate water adsorption tests have been performed on bentonite, but experience has been that the test is time consuming, cumbersome, and extremely sensitive to variations in the test equipment and test conditions. The plate water adsorption test is not recommended for CQC/CQA of soil liners.

Simple, alternative tests that provide an indirect indication of water adsorption are available. One indirect test for water adsorption is measurement of Atterberg (liquid and plastic) limits via ASTM D-4318. The higher the quality of the bentonite, the higher the liquid limit and plasticity index. Although liquid and plastic limits tests are very common for natural soils, they have not been frequently used as indicators of bentonite quality in the bentonite industry. A commonly-used test in the bentonite industry is the free swell test. The free swell test is used to determine the amount of swelling of bentonite when bentonite is exposed to water in a glass beaker. Unfortunately, there is currently no ASTM test for determining free swell of bentonite, although one is under development. Until such time as an ASTM standard is developed, the bentonite supplier may be consulted for a suggested testing procedure.

The liquid limit test and free swell test are recommended as the principal quality control tests for the quality of bentonite being used on a project. There are no widely accepted cutoff values for the liquid limit and free swell. However, the following is offered for the information of CQC and CQA inspectors. The liquid limit of calcium bentonite is frequently in the range of 100 to 150%. Sodium bentonite of medium quality is expected to have a liquid limit of approximately 300 to 500%. High-quality sodium bentonite typically has a liquid limit in the range of about 500 to 700%. According to Brown (1992), calcium bentonites usually have a free swell of less than 6 cc. Low-grade sodium bentonites typically have a free swell of 8 - 15 cc. High-grade bentonites often have free swell values in the range of 18 to 28 cc. If high-grade sodium bentonite is to be used on a project, inspectors should expect that the liquid limit will be ≥ 500% and the free swell will be ≥ 18 cc.

The bentonite must usually also meet gradational requirements. The gradation of the dry bentonite may be determined by carefully sieving the bentonite following procedures outlined in ASTM D-422. The CQA inspector should be particularly careful to ensure that the bentonite has been pulverized to the extent required in the construction specifications. The degree of pulverization is frequently overlooked. Finely-ground, powdered bentonite will behave differently when blended into soil than more coarsely ground, granular bentonite. CQC/CQA personnel should be particularly careful to make sure that the bentonite is sufficiently finely ground and is not delivered in too coarse a form (per project specifications); sieve tests on the raw bentonite received at a job site are recommended to verify gradation of the bentonite.

The bentonite supplier is expected to certify that the bentonite meets the specification requirements. However, CQA inspectors should perform their own tests to ensure compliance with the specifications. The recommended CQA tests and testing frequencies for bentonite quality and gradation are summarized in Table 2.6.

Table 2.6 - Recommended Tests on Bentonite to Determine Bentonite Quality and Gradation

Parameter	Frequency	Test Method
Liquid Limit	1 per Truckload or 2 per Rail Car	ASTM D-4318, "Liquid Limit, Plastic Limit, and Plasticity Index of Soils"
Free Swell	1 per Truckload or 2 per Rail Car	No Standard Procedure Is Available
Grain Size of Dry Bentonite	1 per Truckload or 2 per Rail Car	ASTM D-422, "Particle Size Analysis of Soil"

2.6.5.1 Pugmill Mixing

A pugmill is a device for mixing dry materials. A schematic diagram of a typical pugmill is shown in Fig. 2.30. A conveyor belt feeds soil into a mixing unit, and bentonite drops downward into the mixing unit. The materials are mixed in a large box that contains rotating rods with mixing paddles. Water may be added to the mixture in the pugmill, as well.

The degree of automation of pugmills varies considerably. The most sophisticated pugmills have computer-controlled devices to monitor the amounts of the ingredients being mixed. CQA personnel should monitor the controls on the mixing equipment.

2.6.5.2 In-Place Mixing

An alternative mixing technique is to spread the soil in a loose lift, distribute bentonite on the surface, and mix the bentonite and soil using a rototiller or other mixing equipment. There are several potential problems with in-place mixing. The mixing equipment may not extend to an adequate depth and may not fully mix the loose lift of soil with bentonite. Alternatively, the mixing device may dig too deeply into the ground and actually mix the loose lift in with underlying materials. Bentonite (particularly powdered bentonite) may be blown away by wind when it is placed on the surface of a loose lift, thus reducing the amount of bentonite that is actually incorporated into the soil. The mixing equipment may fail to pass over all areas of the loose lift and may inadequately mix certain portions of the loose lift. Because of these problems many engineers believe that pugmill mixing provides a more reliable means for mixing bentonite with soil. CQA personnel should carefully examine the mixing process to ensure that the problems outlined above, or other problems, do not compromise the quality of the mixing process. Visual examination of the mixture to verify plasticity (see Section 2.5 and Table 2.5) is recommended.

2.6.5.3 Measuring Bentonite Content

The best way to control the amount of bentonite mixed with soil is to measure the relative weights of soil and bentonite blended together at the time of mixing. After bentonite has been mixed with soil there are several techniques available to estimate the amount of bentonite in the soil. None of the techniques are particularly easy to use in all situations.

The recommended technique for measuring the amount of bentonite in soil is the methylene blue test (Alther, 1983). The methylene blue test is a type of titration test. Methylene blue is slowly titrated into a material and the amount of methylene blue required to saturate the material is determined. The more bentonite in the soil the greater the amount of methylene blue that must be added to achieve saturation. A calibration curve is developed between the amount of methylene blue needed to saturate the material and the bentonite content of the soil. The methylene blue test works very well when bentonite is added into a non-clayey soil. However, the amount of methylene blue that must be added to the soil is a function of the amount of clay present in the soil. If clay minerals other than bentonite are present, the clay minerals interfere with the determination of the bentonite content. There is no standard methylene blue test; the procedure outlined in Alther (1983) is suggested until such time as a standard test method is developed.

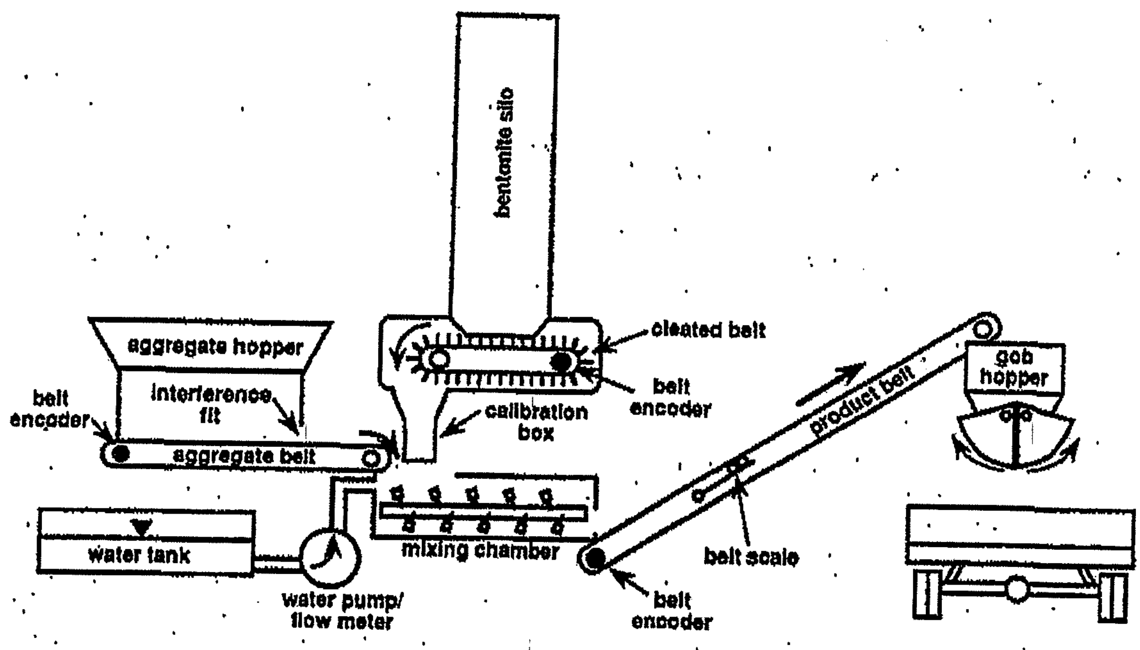


Figure 2.30 - Schematic Diagram of Pugmill

Another type of test that has been used to estimate bentonite content is the filter press test. This test is essentially a water absorbency test: the greater the amount of clay in a soil, the greater the water holding capacity. Like the methylene blue test, the filter press test works well if bentonite is the only source of clay in the soil. No specific test procedure was available at the time of this writing.

Measurement of hydraulic conductivity provides a means for verifying that enough bentonite has been added to the soil to achieve the desired low hydraulic conductivity. If insufficient bentonite has been added, the hydraulic conductivity should be unacceptably large. However, just because the hydraulic conductivity is acceptably low for a given sample does not necessarily mean that the required amount of bentonite has been added to the soil at all locations. Indeed, extra bentonite beyond the minimum amount required is added to soil so that there will be sufficient bentonite present even at those locations that are "lean" in bentonite.

The recommended tests and testing frequencies to verify proper addition of bentonite are summarized in Table 2.7. However, the CQA personnel must realize that the amount of testing depends on the degree of control in the mixing process: the more control during mixing, the less is the need for testing to verify the proper bentonite content.

Table 2.7 - Recommended Tests to Verify Bentonite Content

Parameter	Frequency	Test Method
Methylene Blue Test	1 per 1,000 m^3	Alther (1983)
Compaction Curve for Soil-Bentonite Mixture (Needed To Prepare Hydraulic Conductivity Test Specimen)	1 per 5,000 m^3	Per Project Specifications, e.g., ASTM D-698 or D-1557
Hydraulic Conductivity of Soil-Bentonite Mixture Compacted to Appropriate Water Content and Dry Unit Weight	3/ha/Lift (1/Acre/Lift)	ASTM D-5084, "Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter"

Note: 1 $yd^3 = 0.76\ m^3$

2.6.6 Stockpiling Soils

After the soil has been preprocessed it is usually necessary to ensure that the water content does not change prior to use. The stockpiles can be of any size or shape. Small stockpiles should be covered so that the soil cannot dry or wet. For large stockpiles, it may not be necessary to cover the stockpile, particularly if the stockpile is sloped to promote drainage, moisture is added occasionally to offset drying at the surface, or other steps are taken to minimize wetting or drying of the stockpiled soil.

2.7 Placement of Loose Lift of Soil

After a soil has been fully processed, the soil is hauled to the final placement area. Soil should not be placed in adverse weather conditions, e.g., heavy rain. Inspectors are usually responsible for documenting weather conditions during all earthwork operations. The surface on which the soil will be placed must be properly prepared and the material must be inspected after placement to make sure that the material is suitable. Then the CQA inspectors must also verify that the lift is not too thick. For side slopes, construction specifications should clearly state whether lifts are parallel to the slope or horizontal. For slopes inclined at 3(H):1(V) or flatter, lifts are usually parallel to the slope. For slopes inclined at 2(H):1(V) or steeper, lifts are usually horizontal. However, horizontal lifts may present problems because the hydraulic conductivity for flow parallel to lifts is expected to be somewhat greater than for flow perpendicular to lifts. Details of testing are described in the following subsections.

Transport vehicles can pick up contaminants while hauling material from the borrow source or preprocessing area. If this occurs, measures should be taken to prevent contaminants from falling off transport vehicles into the soil liner material. These measures may include restricting vehicles to contaminant free haul roads or removing contaminants before the vehicle enters the placement area.

2.7.1 Surface Scarification

Prior to placement of a new lift of soil, the surface of the previously compacted lift of soil liner should be roughened to promote good contact between the new and old lifts. Inspectors should observe the condition of the surface of the previously compacted lift to make sure that the surface has been scarified as required in the construction specifications. When soil is scarified it is usually roughened to a depth of about 25 mm (1 in.). In some cases the surface may not require scarification if the surface is already rough after the end of compaction of a lift. It is very important that CQA inspectors ensure that the soil has been properly scarified if construction specifications require scarification. If the soil is scarified, the scarified zone becomes part of the loose lift of soil and should be counted in measuring the loose lift thickness.

2.7.2 Material Tests and Visual Inspection

2.7.2.1 Material Tests

After a loose lift of soil has been placed, samples are periodically taken to confirm the properties of the soil liner material. These samples are in addition to samples taken from the borrow area (Table 2.3). The types of tests and frequency of testing are normally specified in the CQA documents. Table 2.8 summarizes recommended minimum tests and testing frequencies. Samples of soils can be taken either on a grid pattern or on a random sampling pattern (see Section 2.8.3.2). Statistical tests and criteria can be applied but are not usually applied to soil liners in part because enough data have to be gathered to apply statistics, and yet decisions have to be made immediately, before very much data are collected.

2.7.2.2 Visual Observations

Inspectors should position themselves near the working face of soil liner material as it is being placed. Inspectors should look for deleterious materials such as stones, debris, and organic matter. Continuous inspection of the placement of soil liner material is recommended to ensure that the soil liner material is of the proper consistency.

2.7.2.3 Allowable Variations

Tests on soil liner materials may occasionally fail to conform with required specifications. It is unrealistic to think that 100% of a soil liner material will be in complete conformance with specifications. For example, if the construction documents require a minimum plasticity index it may be anticipated that a small fraction of the soil (such as pockets of sandy material) will fail to conform with specifications. It is neither unusual nor unexpected that occasional failing material will be encountered in soil liners. Occasional imperfections in soil liner materials are expected. Indeed, one of the reasons why multiple lifts are used in soil liners is to account for the inevitable variations in the materials of construction employed in building soil liners. Occasional deviations from construction specifications are not harmful. Recommended maximum allowable variations (failing tests) are listed in Table 2.9.

Table 2.8 - Recommended Materials Tests for Soil Liner Materials Sampled after Placement in a Loose Lift (Just Before Compaction)

Parameter	Test Method	Minimum Testing Frequency
Percent Fines (Note 1)	ASTM D-1140	1 per 800 m^3 (Notes 2 & 5)
Percent Gravel (Note 3)	ASTM D-422	1 per 800 m^3 (Notes 2 & 5)
Liquid & Plastic Limits	ASTM D-4318	1 per 800 m^3 (Notes 2 & 5)
Percent Bentonite (Note 4)	Alther (1983)	1 per 800 m^3 (Notes 2 & 5)
Compaction Curve	As Specified	1 per 4,000 m^3 (Note 5)
Construction Oversight	Observation	Continuous

Notes:

1. Percent fines is defined as percent passing the No. 200 sieve.
2. In addition, at least one test should be performed each day that soil is placed, and additional tests should be performed on any suspect material observed by CQA personnel.
3. Percent gravel is defined as percent retained on the No. 4 sieve.
4. This test is only applicable to soil-bentonite liners.
5. 1 $yd^3 = 0.76$ m^3.

Table 2.9 - Recommended Maximum Percentage of Failing Material Tests

Parameter	Maximum Allowable Percentage of Outliers
Atterberg Limits	5% and Outliers Not Concentrated in One Lift or One Area
Percent Fines	5% and Outliers Not Concentrated in One Lift or One Area
Percent Gravel	10% and Outliers Not Concentrated in One Lift or One Area
Clod Size	10% and Outliers Not Concentrated in One Lift or One Area
Percent Bentonite	5% and Outliers Not Concentrated in One Lift or One Area
Hydraulic Conductivity of Laboratory Compacted Soil	5% and Outliers Not Concentrated in One Lift or One Area

2.7.2.4 Corrective Action

If it is determined that the materials in an area do not conform with specifications, the first step is to define the extent of the area requiring repair. A sound procedure is to require the contractor to repair the lift of soil out to the limits defined by passing CQC/CQA tests. The contractor should not be allowed to guess at the extent of the area that requires repair. To define the limits of the area that requires repair, additional tests are often needed. Alternatively, if the contractor chooses not to request additional tests, the contractor should repair the area that extends from the failing test out to the boundaries defined by passing tests.

The usual corrective action is to wet or dry the loose lift of soil in place if the water content is incorrect. The water must be added uniformly, which requires mixing the soil with a disc or rototiller (see Section 2.6.1). If the soil contains oversized material, oversized particles are removed from the material (see Section 2.6.2). If clods are too large, clods can be pulverized in the loose lift (see Section 2.6.3). If the soil lacks adequate plasticity, contains too few fines, contains too much gravel, or lacks adequate bentonite, the material is normally excavated and replaced.

2.7.3 Placement and Control of Loose Lift Thickness

Construction specifications normally place limits on the maximum thickness of a loose lift of soil, e.g., 225 mm (9 in.). The thickness of a loose lift should not exceed this value with normal equipment. The thickness of a loose lift may be determined in several ways. One technique is for an inspector standing near the working face of soil being placed to observe the thickness of the lift. This is probably the most reliable technique for controlling loose lift thickness for CQA inspectors. If there is a question about loose lift thickness one should dig a pit through the loose lift of soil and into the underlying layer. A cross-beam is used to measure the depth from the surface of a loose lift to the top of the previously compacted lift. If the previously compacted lift was scarified, the zone of scarification should be counted in the loose lift thickness for the new layer of soil. Continuous observation of loose lift thickness is recommended during placement of soil liners.

Some earthwork contractors control lift thickness by driving grade stakes into the subsoil and marking the grade stake to indicate the proper thickness of the next layer. This practice is very convenient for equipment operators because they can tell at a glance whether the loose lift thickness is correct. However, this practice is strongly discouraged for the second and subsequent lifts of a soil liner because the penetrations into the previously-compacted lift made by the grade stakes must be repaired. Also, any grade stakes or fragments from grade stakes left in a soil liner could puncture overlying geosynthetics. Repair of holes left by grade stakes is very difficult because one must dig through the loose lift of soil to expose the grade stake, remove the grade stake without breaking the stake and leaving some of the stake in the soil, backfill the hole left by the grade stake, and then replace the loose soil in the freshly-placed lift. For the first lift of soil liner, repair of grade stake holes may not be relevant (depending on the subgrade and what its function is), but grade stakes are discouraged even for the first lift of soil because the stakes may be often broken off and incorporated into the soil. Grade stakes resting on a small platform or base do not need to be driven into the underlying material and are, therefore, much more desirable than ordinary grade stakes. If grade stakes are used, it is recommended that they be numbered and accounted for at the end of each shift; this will provide verification that grade stakes are not being abandoned in the fill material.

The recommended survey procedure for control of lift thickness involves laser sources and receivers. A laser beam source is set at a known elevation, and reception devices held by hand on rods or mounted to grading equipment are used to monitor lift thickness. However, lasers cannot be used at all sites. For instance, the liner may need to be a minimum distance above rock, and the grade lines may follow the contours of underlying rock. Further, every site has areas such as corners, sumps, and boundaries of cells, which preclude the use of lasers.

For those areas where lasers cannot be used, it is recommended that either flexible plastic grade stakes or metallic grade stakes (numbered and inventoried as part of the QA/QC process) be used. It is preferable if the stakes are mounded on a base so that the stakes do not have to be driven into the underlying lift. Repair of grade stake holes should be required; the repairs should be periodically inspected and the repairs documented. Alternatively (and preferably for small areas), spot elevations can be obtained on the surface of a loose lift with conventional level and rod equipment, and adjustments made by the equipment operator based on the levels.

When soil is placed, it is usually dumped into a heap at the working face and spread with dozers. QA/QC personnel should stand in front of the working face to observe the soil for oversized materials or other deleterious material, to visually observe loose lift thickness, and to make sure that the dozer does not damage an underlying layer.

2.8 Remolding and Compaction of Soil

2.8.1 Compaction Equipment

The important parameters concerning compaction equipment are the type and weight of the compactor, the characteristics of any feet on the drum, and the weight of the roller per unit length of drummed surface. Sometimes construction specifications will stipulate a required type of compactor or minimum weight of compactor. If this is the case inspectors should confirm that the compaction equipment is in conformance with specifications. Inspectors should be particularly cognizant of the weight of compactor and length of feet on drummed rollers. Heavy compactors with long feet that fully penetrate a loose lift of soil are generally thought to be the best type of compactor to use for soil liners. Footed rollers may not be necessary or appropriate for some bentonite-soil mixes; smooth-drum rollers or rubber tired rollers may produce best results for soil-bentonite mixtures that do not require kneading or remolding to achieve low hydraulic conductivity but only require densification.

Some compactors are self-propelled while other compactors are towed. Towed, footed rollers are normally ballasted by filling the drum with water to provide weight that will enable significant compactive effort to be delivered to the soil. Inspectors should be very careful to determine whether or not all drums on towed rollers have been filled with liquid.

Compacting soil liners on side slopes can present special challenges, particularly for slopes inclined at 3(H):1(V) or steeper. Inspectors should observe side-slope compaction carefully and watch for any tendency for the compactor to slip down slope or for slippage or cracking to take place in the soil. Inspectors should also be watchful to make sure that adequate compactive effort is delivered to the soil. For soils compacted in lifts parallel to the slope, the first lift of soil should be "knitted" into existing subgrade to minimize a preferential flow path along the interface and to minimize development of a potential slip plane.

Footed rollers can become clogged with soil between the feet. Inspectors should examine the condition of the roller to make sure that the space between feet is not plugged with soil. In addition, compaction equipment is intended to be operated at a reasonable speed. The maximum speed of the compactor should be specified in the construction specifications. CQC and CQA personnel should make sure the speed of the equipment is not too great.

When soils are placed directly on a fragile layer, such as a geosynthetic material, or a drainage material, great care must be taken in placing and compacting the first lift so as not to damage the fragile material or mix clay in with the underlying drainage material. Often, the first lift of soil is considered a sacrificial lift that is placed, spread with dozers, and only nominally compacted with the dozers or a smooth-drum or rubber-tire roller. QA/QC personnel should be particularly careful to observe all placement and compaction operations of the first lift of soil for compacted soil liners placed directly on a geosynthetic material or drainage layer.

It is not uncommon for a contractor to use more than one type of compaction equipment on a project. For example, initial compaction may be with a heavy roller having long feet that fully penetrate a loose lift of soil. Later, the upper part of a lift may be compacted with a heavy rubber-tired roller or other equipment that is particularly effective in compacting near-surface materials.

2.8.2 Number of Passes

The compactive effort delivered by a roller is a function of the number of passes of the roller over a given area of soil. A pass may defined as one pass of the construction equipment or one pass of a drum over a given point in the soil liner. It does not matter whether a pass is defined as a pass of the equipment or a pass of a drum, but the construction specifications and/or CQA plan should define what is meant by a pass. Normally, one pass of the vehicle constitutes a pass for self-propelled rollers and one pass of a drum constitutes a pass for towed rollers.

Some construction documents require a minimum coverage. Coverage (C) is defined as follows:

$$C = [A_f/A_d] \times N \times 100\% \qquad (2.4)$$

where N is the number of passes of the roller, A_f is the sum of the area of the feet on the drums of the roller, and A_d is the area the drum itself. Construction specifications sometimes require 150% -

200% coverage of the roller. For a given roller and minimum percent coverage, the minimum number of passes (N) may be computed.

The number of passes of a compactor over the soil can have an important influence on the overall hydraulic conductivity of the soil liner. It is recommended that periodic observations be made of the number of passes of the roller over a given point. Approximately 3 observations per hectare per lift (one observation per acre per lift) is the recommended frequency of measurement. The minimum number of passes that is reasonable depends upon many factors and cannot be stated in general terms. However, experience has been that at least 5 to 15 passes of a compactor over a given point is usually necessary to remold and compact clay liner materials thoroughly.

2.8.3 Water Content and Dry Unit Weight

2.8.3.1 Water Content and Unit Weight Tests

One of the most important CQA tests is measurement of water content and dry unit weight. Methods of measurement were discussed in Section 2.3. Recommended testing frequencies are listed in Table 2.10. It is stressed that the recommended testing frequencies are the minimum values. Some judgment should be applied to these numbers, and the testing frequencies should be increased or kept at the minimum depending on the specific project and other QA/QC tests and observations. For example, if hydraulic conductivity tests are not performed on undisturbed samples (see Section 2.8.4.2), more water content/density tests may be required than the usual minimum.

2.8.3.2 Sampling Patterns

There are several ways in which sample locations may be selected for water content and unit weight tests. The simplest and least desirable method is for someone in the field to select locations at the time samples must be taken. This is undesirable because the selector may introduce a bias into the sampling pattern. For example, perhaps on the previous project soils of one particular color were troublesome. If the individual were to focus most of the tests on the current project on soils of that same color a bias might be introduced.

A common method of selecting sample locations is to establish a grid pattern. The grid pattern is simple and ensures a high probability of locating defective areas so long as the defective areas are of a size greater than or equal to the spacing between the sampling points. It is important to stagger the grid patterns in successive lifts so that sampling points are not at the same location in each lift. One would not want to sample at the same location in successive lifts because repaired sample penetrations would be stacked on top of one another. The grid pattern sampling procedure is the simplest one to use that avoids the potential for bias described in the previous paragraph.

A third alternative for selecting sampling points is to locate sampling points randomly. Tables and examples are given in Richardson (1992). It is recommended that no sampling point be located within 2 meters of another sampling point. If a major portion of the area to be sampled has been omitted as a result of the random sampling process, CQA inspectors may add additional points to make sure the area receives some testing. Random sampling is sometimes preferred on large projects where statistical procedures will be used to evaluate data. However, it can be demonstrated that for a given number of sampling points, a grid pattern will be more likely to detect a problem area provided that the dimensions of the problem area are greater than or equal to the spacing between sampling points. If the problem area is smaller than the spacing between sampling points, the probability of locating the problem area is approximately the same with both a grid pattern and a random pattern of sampling.

Table 2.10 - Recommended Tests and Observations on Compacted Soil

Parameter	Test Method	Minimum Testing Frequency
Water Content (Rapid) (Note 1)	ASTM D-3017 ASTM D-4643 ASTM D-4944 ASTM D-4959	13/ha/lift (5/acre/lift) (Notes 2 & 7)
Water Content (Note 3)	ASTM D-2216	One in every 10 rapid water content tests (Notes 3 & 7)
Total Density (Rapid) (Note 4)	ASTM D-2922 ASTM D-2937	13/ha/lift (5/acre/lift) (Notes 2, 4 & 7)
Total Density (Note 5)	ASTM D-1556 ASTM D-1587 ASTM D-2167	One in every 20 rapid density tests (Notes 5, 6, & 7)
Number of Passes	Observation	3/ha/lift (1/acre/lift) (Notes 2 & 7)
Construction Oversight	Observation	Continuous

Notes:

1. ASTM D-3017 is a nuclear method, ASTM D-4643 is microwave oven drying, ASTM D-4944 is a calcium carbide gas pressure tester method, and ASTM D-4959 is a direct heating method. Direct water content determination (ASTM D-2216) is the standard against which nuclear, microwave, or other methods of measurements are calibrated for on-site soils.

2. In addition, at least one test should be performed each day soil is compacted and additional tests should be performed in areas for which CQA personnel have reason to suspect inadequate compaction.

3. Every tenth sample tested with ASTM D-3017, D-4643, D-4944, or D-4959 should be also tested by direct oven drying (ASTM D-2216) to aid in identifying any significant, systematic calibration errors.

4. ASTM D-2922 is a nuclear method and ASTM D-2937 is the drive cylinder method. These methods, if used, should be calibrated against the sand cone (ASTM D-1556) or rubber balloon (ASTM D-2167) for on-site soils. Alternatively, the sand cone or rubber balloon method can be used directly.

5. Every twentieth sample tested with D-2922 should also be tested (as close as possible to the same test location) with the sand cone (ASTM D-1556) or rubber balloon (ASTM D-2167) to aid in identifying any systematic calibration errors with D-2922.

6. ASTM D-1587 is the method for obtaining an undisturbed sample. The section of undisturbed sample can be cut or trimmed from the sampling tube to determine bulk density. This method should not be used for soils containing any particles > 1/6-th the diameter of the sample.

7. 1 acre = 0.4 ha.

No matter which method of determining sampling points is selected, it is imperative that CQA inspectors have the responsibility to perform additional tests on any suspect area. The number of additional testing locations that are appropriate varies considerably from project to project.

2.8.3.3 Tests with Different Devices to Minimize Systematic Errors

Some methods of measurement may introduce a systematic error. For example, the nuclear device for measuring water content may consistently produce a water content measurement that is too high if there is an extraneous source of hydrogen atoms besides water in the soil. It is important that devices that may introduce a significant systematic error be periodically correlated with measurements that do not have such error. Water content measurement tests have the greatest potential for systematic error. Both the nuclear method as well as microwave oven drying can produce significant systematic error under certain conditions. Therefore, it is recommended that if the nuclear method or any of the rapid methods of water content measurement (Table 2.2) are used to measure water content, periodic correlation tests should be made with conventional overnight oven drying (ASTM D-2216).

It is suggested that at the beginning of a project, at least 10 measurements of water content be determined on representative samples of the site-specific soil using any rapid measurement method to be employed on the project as well as ASTM D-2216. After this initial correlation, it is suggested (see Tables 2.10) that one in ten rapid water content tests be crossed check with conventional overnight oven drying. At the completion of a project a graph should be presented that correlates the measured water content with a rapid technique against the water content from conventional overnight oven drying.

Some methods of unit weight measurement may also introduce bias. For example, the nuclear device may not be properly calibrated and could lead to measurement of a unit weight that is either too high or too low. It is recommended that unit weight be measured independently on occasion to provide a check against systematic errors. For example, if the nuclear device is the primary method of density measurement being employed on a project, periodic measurements of density with the sand cone or rubber balloon device can be used to check the nuclear device. Again, a good practice is to perform about 10 comparative tests on representative soil prior to construction. During construction, one in every 20 density tests (see Table 2.10) should be checked with the sand cone or rubber balloon. A graph should be made of the unit weight measured with the nuclear device versus the unit weight measured with the sand cone or rubber balloon device to show the correlation. One could either plot dry unit weight or total unit weight for the correlation. Total unit weight in some ways is more sensible because the methods of measurement are actually total unit weight measurements; dry unit weight is calculated from the total unit weight and water content (Eq. 2.1.).

2.8.3.4 Allowable Variations and Outliers

There are several reasons why a field water content or density test may produce a failing result, i.e., value outside of the specified range. Possible causes for a variation include a human error in measurement of water content or dry unit weight, natural variability of the soil or the compaction process leading to an anomaly at an isolated location, limitations in the sensitivity and repeatability of the test methods, or inadequate construction procedures that reflect broader-scale deficiencies.

Measurement errors are made on every project. From time to time it can be expected that CQC and CQA personnel will incorrectly measure either the water content or the dry unit weight.

Periodic human errors are to be expected and should be addressed in the CQA plan.

If it is suspected that a test result is in error, the proper procedure for rectifying the error should be as follows. CQC or CQA personnel should return to the point where the questionable measurement was obtained. Several additional tests should be performed in close proximity to the location of the questionable test. If all of the repeat tests provide satisfactory results the questionable test result may be disregarded as an error. Construction quality assurance documents should specify the number of tests required to negate a blunder. It is recommended that approximately 3 passing tests be required to negate the results of a questionable test.

One of the main reasons why soil liners are built of multiple lifts is a realization that the construction process and the materials themselves vary. With multiple lifts no one particular point in any one lift is especially significant even if that point consists of unsatisfactory material or improperly compacted material. It should be expected that occasional deviations from construction specifications will be encountered for any soil liner. In fact, if one were to take enough soil samples, one can rest assured that a failing point on some scale would be located.

Measurement techniques for compacted soils are imperfect and produce variable results. Turnbull et al. (1966) discuss statistical quality control for compacted soils. Noorany (1990) describes 3 sites in the San Diego area for which 9 testing laboratories measured water content and percent compaction on the same fill materials. The ranges in percent compaction were very large: 81-97% for Site 1, 77-99% for Site 2, and 89-103% for Site 3.

Hilf (1991) summarizes statistical data from 72 earth dams; the data show that the standard deviation in water content is typically 1 to 2%, and the standard deviation in dry density is typically 0.3 to 0.6 kN/m^3 (2 to 4 pcf). Because the standard deviations are themselves on the same order as the allowable range of these parameters in many earthwork specifications, it is statistically inevitable that there will be some failing tests no matter how well built the soil liner is.

It is unrealistic to expect that 100% of all CQA tests will be in compliance with specifications. Occasional deviations should be anticipated. If there are only a few randomly-located failures, the deviations in no way compromise the quality or integrity of a multiple-lift liner.

The CQA documents may provide an allowance for an occasional failing test. The documents may stipulate that failing tests not be permitted to be concentrated in any one lift or in any one area. It is recommended that a small percentage of failing tests be allowed rather than insisting upon the unrealistic requirement that 100% of all tests meet project objectives. Statistically based requirements provide a convenient yet safe and reliable technique for handling occasional failing test results.. However, statistically based methods require that enough data be generated to apply statistics reliably. Sufficient data to apply statistical methods may not be available, particularly in the early stages of a project.

Another approach is to allow a small percentage of outliers but to require repair of any area where the water content is far too low or high or the dry unit weight is far too low. This approach is probably the simplest to implement -- recommendations are summarized in Table 2.11.

Table 2.11 - Recommended Maximum Percentage of Failing Compaction Tests

Parameter	Maximum Allowable Percentage of Outliers
Water Content	3% and Outliers Not Concentrated in One Lift or One Area, and No Water Content Less than 2% or More than 3% of the Allowable Value
Dry Density	3% and Outliers Not Concentrated in One Lift or One Area, and No Dry Density Less than 0.8 kN/m^3 (5 pcf) Below the Required Value
Number of Passes	5% and Outliers Not Concentrated in One Lift or One Area

2.8.3.5 Corrective Action

If it is determined that an area does not conform with specifications and that the area needs to be repaired, the first step is to define the extent of the area requiring repair. The recommended procedure is to require the contractor to repair the lift of soil out to the limits defined by passing CQC and CQA tests. The contractor should not be allowed to guess at the extent of the area that requires repair. To define the limits of the area that requires repair, additional tests are often needed. Alternatively, if the contractor chooses not to request additional tests, the contractor should repair the area that extends from the failing test out to the boundaries defined by passing tests.

The usual problem requiring corrective action at this stage is inadequate compaction of the soil. The contractor is usually able to rectify the problem with additional passes of the compactor over the problem area.

2.8.4 Hydraulic Conductivity Tests on Undisturbed Samples

Hydraulic conductivity tests are often performed on "undisturbed" samples of soil obtained from a single lift of compacted soil liner. Test specimens are trimmed from the samples and are permeated in the laboratory. Compliance with the stated hydraulic conductivity criterion is checked.

This type of test is given far too much weight in most QA programs. Low hydraulic conductivity of samples taken from the liner is necessary for a well-constructed liner but is not sufficient to demonstrate that the large-scale, field hydraulic conductivity is adequately low. For example, Elsbury et al. (1990) measured hydraulic conductivities on undisturbed samples of a poorly constructed liner that averaged 1×10^{-9} cm/s, and yet the actual in-field value was 1×10^{-5} cm/s. The cause for the discrepancy was the existence of macro-scale flow paths in the field that were not simulated in the small-sized (75 mm or 3 in. diameter) laboratory test specimens.

Not only does the flow pattern through a 75-mm-diameter test specimen not necessarily reflect flow patterns on a larger field scale, but the process of obtaining a sample for testing inevitably disturbs the soil. Layers are distorted, and gross alterations occur if significant gravel is present in the soil. The process of pushing a sampling tube into the soil densifies the soil, which lowers its hydraulic conductivity. The harder and drier the soil, the greater the disturbance. As a result of these various factors, the large-scale, field hydraulic conductivity is almost always greater than or equal to the small-scale, laboratory-measured hydraulic conductivity. The difference between values from a small laboratory scale and a large field scale depends on the quality of construction -- the better the quality of construction, the less the difference.

Laboratory hydraulic conductivity tests on undisturbed samples of compacted liner can be valuable in some situations. For instance, for soil-bentonite mixes, the laboratory test provides a check on whether enough bentonite has been added to the mix to achieve the desired hydraulic conductivity. For soil liners in which a test pad is not constructed, the laboratory tests provide some verification that appropriate materials have been used and compaction was reasonable (but hydraulic conductivity tests by themselves do not prove this fact).

Laboratory hydraulic conductivity tests constitute a major inconvenience because the tests usually take at least several days, and sometimes a week or two, to complete. Their value as QA tools is greatly diminished by the long testing time -- field construction personnel simply cannot wait for the results of the tests to proceed with construction, nor would the QA personnel necessarily want them to wait because opportunities exist for damage of the liner as a result of desiccation. Thus, one should give very careful consideration as to whether the laboratory hydraulic conductivity tests are truly needed for a given project and will serve a sufficiently useful purpose to make up for the inconvenience of this type of test.

Research is currently underway to determine if larger-sized samples from field-compacted soils can give more reliable results than the usual 75-mm (3 in.) diameter samples. Until further data are developed, the following recommendations are made concerning the approach to utilizing laboratory hydraulic conductivity tests for QA on field-compacted soils:

1. For gravely soils or other soils that cannot be consistently sampled without causing significant disturbance, laboratory hydraulic conductivity tests should not be a part of the QA program because representative samples cannot realistically be obtained. A test pad (Section 2.10) is recommended to verify hydraulic conductivity.

2. If a test pad is constructed and it is demonstrated that the field-scale hydraulic conductivity is satisfactory on the test pad, the QA program for the actual soil liner should focus on establishing that the actual liner is built of similar materials and to equal or better standards compared to the test pad -- laboratory hydraulic conductivity testing is not necessary to establish this.

3. If no test pad is constructed and it is believed that representative samples can be obtained for hydraulic conductivity testing, then laboratory hydraulic conductivity tests on undisturbed samples from the field are recommended.

2.8.4.1 Sampling for Hydraulic Conductivity Testing

A thin-walled tube is pushed into the soil to obtain a sample. Samples of soil should be taken in the manner that minimizes disturbance such as described in ASTM D-1587. Samples should be sealed and carefully stored to prevent drying and transported to the laboratory in a manner that minimizes soil disturbance as described in ASTM D-4220.

It is particularly important that the thin-walled sampling tube be pushed into the soil in the direction perpendicular to the plane of compaction. Many CQA inspectors will push the sampling tube into the soil using the blade of a dozer or compactor. This practice is not recommended because the sampling tube tends to rotate when it is pushed into the soil. The recommended way of sampling the soil is to push the sampling tube straight into the soil using a jack to effect a smooth, straight push.

Sampling of gravely soils for hydraulic conductivity testing is often a futile exercise. The gravel particles that are encountered by the sampling tube tend to tumble and shear during the push, which caused major disturbance of the soil sample. Experience has been that QA/QC personnel may take several samples of gravely soil before a sample that is sufficiently free of gravel to enable proper sampling is finally obtained; in these cases, the badly disturbed, gravely samples are discarded. Clearly, the process of discarding samples because they contain too much gravel to enable proper sampling introduces a bias into the process. Gravely soils are not amenable to undisturbed sampling.

2.8.4.2 Hydraulic Conductivity Testing

Hydraulic conductivity tests are performed utilizing a flexible wall permeameter and the procedures described in ASTM D-5084. Inspectors should be careful to make sure that the effective confining stress utilized in the hydraulic conductivity test is not excessive. Application of excessive confining stress can produce an artificially low hydraulic conductivity. The CQA plan should prescribe the maximum effective confining stress that will be used; if none is specified a value of 35 kPa (5 psi) is recommended for both liner and cover systems.

2.8.4.3 Frequency of Testing

Hydraulic conductivity tests are typically performed at a frequency of 3 tests/ha/lift (1 test/acre/lift) or, for very thick liners (≥ 1.2 m or 4 ft) per every other lift. This is the recommended frequency of testing, if hydraulic conductivity testing is required. The CQA plan should stipulate the frequency of testing.

2.8.4.4 Outliers

The results of the above-described hydraulic conductivity tests are often given far too much weight. A passing rate of 100% does not necessarily prove that the liner was well built, yet some inexperienced individuals falsely believe this to be the case. Hydraulic conductivity tests are performed on small samples; even though small samples may have low hydraulic conductivity, inadequate construction or CQA can leave remnant macro-scale defects such as fissures and pockets of poorly compacted soil. The fundamental problem is that laboratory hydraulic conductivity tests are usually performed on 75-mm (3 in.) diameter samples, and these samples are too small to contain a representative distribution of macro-scale defects (if any such defects are present). By the same token, an occasional failing test does not necessarily prove that a problem exists. An occasional failing test only shows that either: (1) there are occasional zones that fail to meet performance criteria, or (2) sampling disturbance (e.g., from the sampling tube shearing stones in the soil) makes confirmation of low hydraulic conductivity difficult or impossible. Soil liners built of multiple lifts are expected to have occasional, isolated imperfections -- this is why the liners are constructed from multiple lifts. Thus, occasional failing hydraulic conductivity tests by themselves do not mean very much. Even on the best built liners, occasional failing test results should be anticipated.

It is recommended that a multiple-lift soil liner be considered acceptable even if a small percentage (approximately 5%) of the hydraulic conductivity tests fail. However, one should allow a small percentage of hydraulic conductivity failures only if the overall CQA program is thorough. Further, it is recommended that failing samples have a hydraulic conductivity that is no greater than one-half to one order of magnitude above the target maximum value. If the hydraulic conductivity at a particular point is more than one-half to one order of magnitude too high, the zone should be retested or repaired regardless of how isolated it is.

2.8.5 Repair of Holes from Sampling and Testing

A number of tests, e.g., from nuclear density tests and sampling for hydraulic conductivity, require that a penetration be made into a lift of compacted soil. It is extremely important that all penetrations be repaired. The recommended procedure for repair is as follows. The backfill material should first be selected. Backfill may consist of the soil liner material itself, granular or pelletized bentonite, or a mixture of bentonite and soil liner material. The backfill material should be placed in the hole requiring repair with a loose lift thickness not exceeding about 50 mm (2 in.). The loose lift of soil should be tamped several times with a steel rod or other suitable device that compacts the backfill and ensures no bridging of material that would leave large air pockets. Next, a new lift of backfill should be placed and compacted. The process is repeated until the hole has been filled.

Because it is critical that holes be properly repaired, it is recommended that periodic inspections and written records made of the repair of holes. It is suggested that approximately 20% of all the repairs be inspected and that the backfill procedures be documented for these inspections. It is recommended that the inspector of repair of holes not be the same person who backfilled the hole.

2.8.6 Final Lift Thickness

Construction documents may place restrictions on the maximum allowable final (after-compaction) lift thickness. Typically, the maximum thickness is 150 mm (6 in.). Final elevation surveys should be used to establish thicknesses of completed earthwork segments. The specified maximum lift thickness is a nominal value. The actual value may be determined by surveys on the surface of each completed lift, but an acceptable practice (provided there is good CQA on loose lift thickness) is to survey the liner after construction and calculate the average thickness of each lift by dividing the total thickness by the number of lifts.

Tolerances should be specified on final lift thickness. Occasional outliers from these tolerances are not detrimental to the performance of a multi-lift liner. It is recommended by analogy to Table 2.9 that no more than 5% of the final lift thickness determinations be out of specification and that no out-of-specification thickness be more than 25 mm (1 in.) more than the maximum allowable lift thickness.

2.8.7 Pass/Fail Decision

After all CQA tests have been performed, a pass/fail decision must be made. Procedures for dealing with materials problems were discussed in Section 2.7.2.4. Procedures for correcting deficiencies in compaction of the soil were addressed in Section 2.8.3.5. A final pass/fail decision is made by the CQA engineer based upon all the data and test results. The hydraulic conductivity test results may not be available for several days after construction of a lift has been completed. Sometimes the contractor proceeds at risk with placement of additional lifts before all test results are available. On occasion, construction of a liner proceeds without final results from a test pad on the assumption that results will be acceptable. If a "fail" decision is made at this late stage, the defective soil plus any overlying materials that have been placed should be removed and replaced.

2.9 Protection of Compacted Soil

2.9.1 Desiccation

2.9.1.1 Preventive Measures

There are several ways to prevent compacted soil liner materials from desiccating. The soil may be smooth rolled with a steel drummed roller to produce a thin, dense skin of soil on the surface. This thin skin of very dense soil helps to minimize transfer of water into or out of the underlying material. However, the smooth-rolled surface should be scarified prior to placement of a new lift of soil.

A far better preventive measure is to water the soil periodically. Care must be taken to deliver water uniformly to the soil and not to create zones of excessively wet soil. Adding water by hand is not recommended because water is not delivered uniformly to the soil.

An alternative preventive measure is to cover the soil temporarily with a geomembrane, moist geotextile, or moist soil. The geomembrane or geotextile should be weighted down with sand bags or other materials to prevent transfer of air between the geosynthetic cover and soil. If a geomembrane is used, care should be taken to ensure that the underlying soil does not become heated and desiccate; a light-colored geomembrane may be needed to prevent overheating. If moist soil is placed over the soil liner, the moist soil is removed using grading equipment.

2.9.1.2 Observations

Visual observation is the best way to ensure that appropriate preventive measures have been taken to minimize desiccation. Inspectors should realize that soil liner materials can dry out very quickly (sometimes in a matter of just a few hours). Inspectors should be aware that drying may occur over weekends and provisions should be made to provide appropriate observations.

2.9.1.3 Tests

If there are questions about degree of desiccation, tests should be performed to determine the water content of the soil. A decrease in water content of one to two percentage points is not considered particularly serious and is within the general accuracy of testing. However, larger reductions in water content provide clear evidence that desiccation has taken place.

2.9.1.4 Corrective Action

If soil has been desiccated to a depth less than or equal to the thickness of a single lift, the desiccated lift may be disked, moistened, and recompacted. However, disking may produce large, hard clods of clay that will require pulverization. Also, it should be recognized that if the soil is wetted, time must be allowed for water to be absorbed into the clods of clay and hydration to take place uniformly. For this reason it may be necessary to remove the desiccated soil from the construction area, to process the lift in a separate processing area, and to replace the soil accordingly.

2.9.2 Freezing Temperatures

2.9.2.1 Compacting Frozen Soil

Frozen soil should never be used to construct soil liners. Frozen soils form hard pieces that cannot be properly remolded and compacted. Inspectors should be on the lookout for frozen chunks of soil when construction takes place in freezing temperatures.

2.9.2.2 Protection After Freezing

Freezing of soil liner materials can produce significant increases in hydraulic conductivity. Soil liners must be protected from freezing before and after construction. If superficial freezing takes place on the surface of a lift of soil, the surface may be scarified and recompacted. If an entire lift has been frozen, the entire lift should be disked, pulverized, and recompacted. If the soil is frozen to a depth greater than one lift, it may be necessary to strip away and replace the frozen material.

2.9.2.3 Investigating Possible Frost Damage

Inspectors usually cannot determine from an examination of the surface the depth to which freezing took place in a completed or partially completed soil liner that has been exposed to freezing. In such cases it may be necessary to investigate the soil liner material for possible frost damage. The extent of damage is difficult to determine. Freezing temperatures cause the development of tiny microcracks in the soil. Soils that have been damaged due to frost action develop fine cracks that lead to the formation of chunks of soil when the soil is excavated. The pushing of a sampling tube into the soil will probably close these cracks and mask the damaging effects of frost upon hydraulic conductivity. The recommended procedure for evaluating possible frost damage to soil liners involves three steps:

1. Measure the water content of the soil within and beneath the zone of suspected frost damage. Density may also be measured, but freeze/thaw has little effect on density and may actually cause an increase in dry unit weight. Freeze/thaw is often accompanied by desiccation; water content measurements will help to determine whether drying has taken place.

2. Investigate the morphology of the soil by digging into the soil and examining its condition. Soil damaged by freezing usually contains hairline cracks, and the soil breaks apart in chunks along larger cracks caused by freeze/thaw. Soil that has not been frozen should not have tiny cracks nor should it break apart in small chunks. The morphology of the soil should be examined by excavating a small pit into the soil liner and peeling off sections from the wall of the pit. One should not attempt to cut pieces from the sidewall; smeared soil will mask cracks. A distinct depth may be obvious; above this depth the soil breaks into chunks along frost-induced cracks, and below this depth there is no evidence of cracks produced by freezing.

3. One or more samples of soil should be carefully hand trimmed for hydraulic conductivity testing. The soil is usually trimmed with the aid of a sharpened section of tube of the appropriate inside diameter. The tube is set on the soil surface with the sharpened end facing downward, soil is trimmed away near the sharpened edge of the trimming ring, the tube is pushed a few millimeters into the soil, and the trimming is repeated. Samples may be taken at several depths to delineate the depth to which freeze/thaw damage occurred. The minimum diameter of a cylindrical test specimen should be 300 mm (12 in.). Small test specimens, e.g., 75 mm (3 in.) diameter specimens, should not be used because freeze/thaw can create morphological structure in the soil on a scale too large to permit representative testing with small samples. Hydraulic conductivity tests should be performed as described in ASTM D-5084. The effective confining stress should not exceed the

smallest vertical effective stress to which the soil will be subjected in the field, which is usually the stress at the beginning of service for liners. If no compressive stress is specified, a value of 35 kPa (5 psi) is recommended for both liner and cover system.

The test pit and all other penetrations should be carefully backfilled by placing soil in lifts and compacting the lifts. The sides of the test pit should be sloped so that the compactor can penetrate through to newly placed material without interference from the walls of the pit.

2.9.2.4 Repair

If it is determined that soil has been damaged by freezing, the damaged material is usually repaired as follows. If damage is restricted to a single lift, the lift may be disked, processed to adjust water content or to reduce clod size if necessary, and recompacted. If the damage extends deeper, damaged materials should be excavated and replaced.

2.9.3 Excess Surface Water

In some cases exposed lifts of liner material, or the completed liner, are subjected to heavy rains that soften the soil. Surface water creates a problem if the surface is uneven (e.g., if a footed roller has been used and the surface has not been smooth-rolled with a smooth, steel wheeled roller) -- numerous small puddles of water will develop in the depressions low areas. Puddles of water should be removed before further lifts of material, or other components of the liner or cover system, are constructed. The material should be disked repeatedly to allow the soil to dry, and when the soil is at the proper water content, the soil should be compacted. Alternatively, the wet soil may be removed and replaced.

Even if puddles have not formed, the soils may be too soft to permit construction equipment to operate on the soil without creating ruts. To deal with this problem, the soil may be allowed to dry slightly by natural processes (but care must be taken to ensure that it does not dry too much and does not crack excessively during the drying process). Alternatively, the soil may be disked, allowed to dry while it is periodically disked, and then compacted.

If soil is reworked and recompacted, QA/QC tests should be performed at the same frequency as for the rest of the project. However, if the area requiring reworking is very small, e.g., in a sump, tests should be performed in the confined area to confirm proper compaction even if this requires sampling at a greater frequency.

2.10 Test Pads

2.10.1 Purpose of Test Pads

The purpose of a test pad is to verify that the materials and methods of construction proposed for a project will lead to a soil liner with the required large-scale, in-situ, hydraulic conductivity. Unfortunately, it is impractical to perform large-scale hydraulic conductivity tests on the actual soil liner for two reasons: (1) the testing would produce significant physical damage to the liner, and the repair of the damage would be questionable; and (2) the time required to complete the testing would be too long -- the liner could become damaged due to desiccation while one waited for the test results.

A test pad may also be used to demonstrate that unusual materials or construction procedures will work. The process of constructing and testing a test pad is usually a good learning experience for the contractor and CQC/CQA personnel; overall quality of a project is usually elevated as a result of building and testing the test pad.

A test pad is constructed with the soil liner materials proposed for a project utilizing preprocessing procedures, construction equipment, and construction practices that are proposed for the actual liner. If the required hydraulic conductivity is demonstrated for the test pad, it is assumed that the actual liner will have a similar hydraulic conductivity, provided the actual liner is built of similar materials and to standards that equal or exceed those used in building the test pad. If a test pad is constructed and hydraulic conductivity is verified on the test pad, a key goal of CQA/CQC for the actual liner is to verify that the actual liner is built of similar materials and to standards that equal or exceed those used in building the test pad.

2.10.2 Dimensions

Test pads (Fig. 2.31) normally measure about 10 to 15 m in width by 15 to 30 m in length. The width of the test pad is typically at least four times the width of the compaction equipment, and the length must be adequate for the compactor to reach normal operating speed in the test area. The thickness of a test pad is usually no less than the thickness of the soil liner proposed for a facility but may be as little as 0.6 to 0.9 m (2 to 3 feet) if thicker liners are to be employed at full scale. A freely draining material such as sand is often placed beneath the test pad to provide a known boundary condition in case infiltrating water from a surface hydraulic conductivity test (e.g., sealed double ring infiltrometer) reaches the base of the liner. The drainage layer may be drained with a pipe or other means. However, infiltrating water will not reach the drainage layer if the hydraulic conductivity is very low; the drainage pipe would only convey water if the hydraulic conductivity turns out to be very large. The sand drainage material may not provide adequate foundation support for the first lift of soil liner unless the sand is compacted sufficiently. Also, the first lift of soil liner material on the drainage layer is often viewed as a sacrificial lift and is only compacted nominally to avoid mixing clayey soil in with the drainage material.

2.10.3 Materials

The test pad is constructed of the same materials that are proposed for the actual project. Processing equipment and procedures should be identical, too. The same types of CQC/CQA tests that will be used for the soil liner are performed on the test pad materials. If more than one type of material will be used, one test pad should be constructed for each type of material.

2.10.4 Construction

It is recommended that test strips be built before constructing the test pad. Test strips allow for the detection of obvious problems and provide an opportunity to fine-tune soil specifications, equipment selection, and procedures so that problems are minimized and the probability of the required hydraulic conductivity being achieved in the test pad is maximized. Test strips are typically two lifts thick, one and a half to two equipment widths wide, and about 10 m (30 ft) long.

The test pad is built using the same loose lift thickness, type of compactor, weight of compactor, operating speed, and minimum number of passes that are proposed for the actual soil liner. It is important that the test pad not be built to standards that will exceed those used in building the actual liner. For example, if the test pad is subjected to 15 passes of the compactor, one would want the actual soil liner to be subjected to at least 15 passes as well. It is critical that CQA personnel document the construction practices that are employed in building the test pad. It is best if the same contractor builds the test pad and actual liner so that experience gained from the test pad process is not lost. The same applies to CQC and CQA personnel.

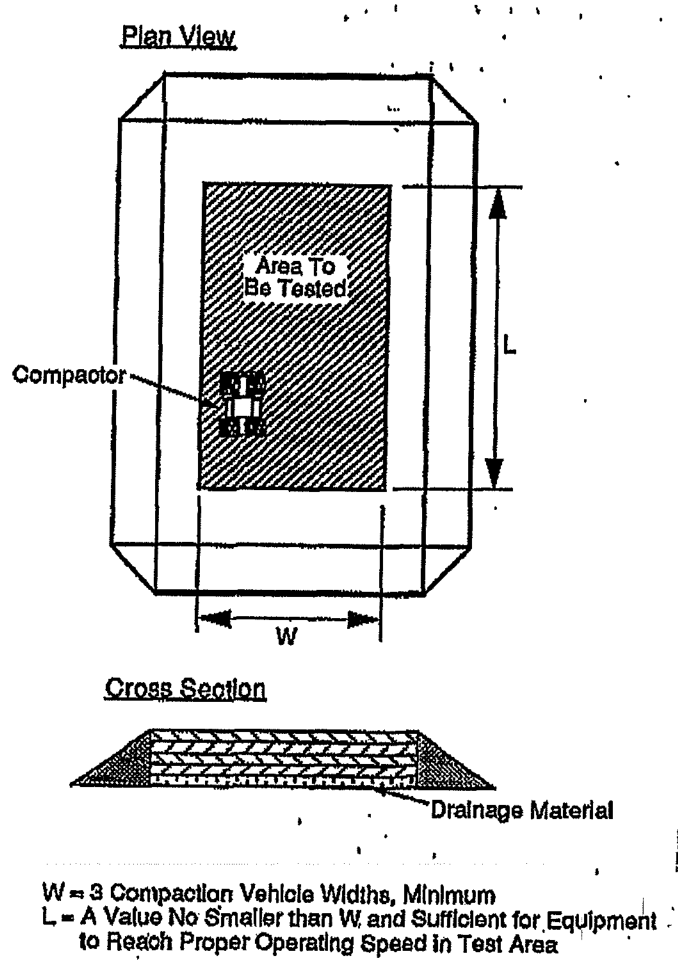


Figure 2.31 - Schematic Diagram of Soil Liner Test Pad

2.10.5 Protection

The test pad must be protected from desiccation, freezing, and erosion in the area where in situ hydraulic conductivity testing is planned. The recommended procedure is to cover the test pad with a sheet of white or clear plastic and then either spread a thin layer of soil on the plastic if no rain is anticipated or, if rain may create an undesirably muddy surface, cover the plastic with hay or straw.

2.10.6 Tests and Observations

The same types of CQA tests that are planned for the actual liner are usually performed on the test pad. However, the frequency of testing is usually somewhat greater for the test pad. Material tests such as liquid limit, plastic limit, and percent fines are often performed at the rate of one per lift. Several water content-density tests are usually performed per lift on the compacted soil. A typical rate of testing would be one water content-density test for each 40 m^2 (400 ft^2). The CQA plan should describe the testing frequency for the test pad.

There is a danger in over testing the test pad -- excessive testing could lead to a greater degree of construction control in the test pad than in the actual liner. The purpose of the test pad is to verify that the materials and methods of construction proposed for a project can result in compliance with performance objectives concerning hydraulic conductivity. Too much control over the construction of the test pad runs counter to this objective.

2.10.7 In Situ Hydraulic Conductivity

2.10.7.1 Sealed Double-Ring Infiltrometer

The most common method of measuring in situ hydraulic conductivity on test pads is the sealed double-ring infiltrometer (SDRI). A schematic diagram of the SDRI is shown Fig. 2.32. The test procedure is described in ASTM D-5093.

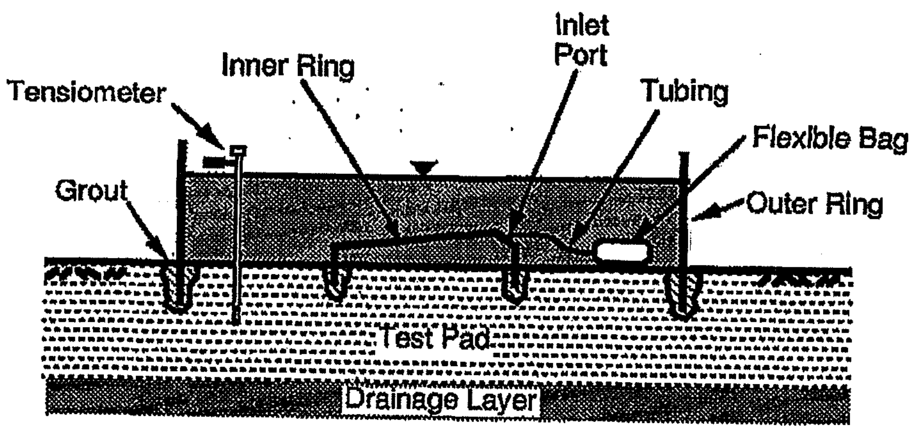


Figure 2.32 - Schematic Diagram of Sealed Double Ring Infiltrometer (SDRI)

With this method, the quantity of water that flows into the test pad over a known period of time is measured. This flow rate, which is called the infiltration rate (I), is computed as follows:

$$I = Q/At \qquad (2.5)$$

where Q is the quantity of water entering the surface of the soil through a cross-sectional area A and over a period of time t.

Hydraulic conductivity (K) is computed from the infiltration rate and hydraulic gradient (i) as follows:

$$K = I/i \tag{2.6}$$

Three procedures have been used to compute the hydraulic gradient. The procedures are called (1) apparent gradient method; (2) wetting front method; and (3) suction head method. The equation for computing hydraulic gradient from each method is shown in Fig. 2.33.

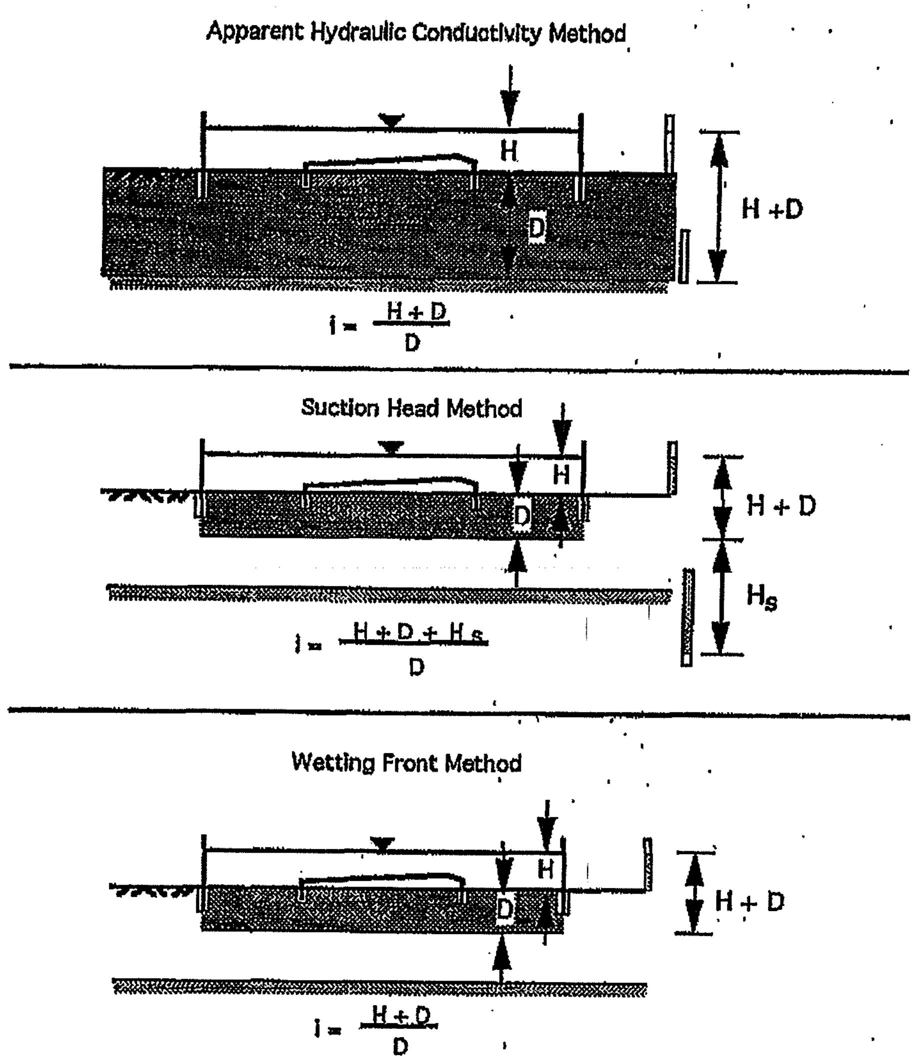


Figure 2.33 - Three Procedures for Computing Hydraulic Gradient from Infiltration Test

The apparent gradient method is the most conservative of the three methods because this method yields the lowest estimate of i and, therefore, the highest estimate of hydraulic conductivity. The apparent gradient method assumes that the test pad is fully soaked with water over the entire depth of the test pad. For relatively permeable test pads, the assumption of full soaking is reasonable, but for soil liners with $K < 1 \times 10^{-7}$ cm/s, the assumption of full soaking is excessively conservative and should not be used unless verified.

The second and most widely used method is the wetting front method. The wetting front is assumed to partly penetrate the test pad (Fig. 2.33) and the water pressure at the wetting front is conservatively assumed to equal atmospheric pressure. Tensiometers are used to monitor the depth of wetting of the soil over time, and the variation of water content with depth is determined at the end of the test. The wetting front method is conservative but in most cases not excessively so. The wetting front method is the method that is usually recommended.

The third method, called the suction head method, is the same as the wetting front method except that the water pressure at the wetting front is not assumed to be atmospheric pressure. The suction head (which is defined as the negative of the pressure head) at the wetting front is H_s and is added to the static head of water in the infiltration ring to calculate hydraulic gradient (Fig. 2.37). The suction head H_s is identical to the wetting front suction head employed in analyzing water infiltration with the Green-Ampt theory. The suction head H_s is not the ambient suction head in the unsaturated soil and is generally very difficult to determine (Brakensiek, 1977). Two techniques available for determining H_s are:

1. Integration of the hydraulic conductivity function (Neuman, 1976):

$$H_s = \int_{h_{sc}}^{0} K_r dh_s \tag{2.7}$$

   where h_{sc} is the suction head at the initial (presoaked) water content of the soil, K_r is the relative hydraulic conductivity (K at particular suction divided by the value of K at full saturation), and h_s is suction.

2. Direct measurement with air entry permeameter (Daniel, 1989, and references therein).

Reimbold (1988) found that H_s was close to zero for two compacted soil liner materials. Because proper determination of H_s is very difficult, the suction head method cannot be recommended, unless the testing personnel take the time and make the effort to determine H_s properly and reliably.

Corrections may be made to account for various factors. For example, if the soil swells, some of the water that infiltrated into the soil was absorbed into the expanded soil. No consensus exists on various corrections and these should be evaluated case by case.

2.10.7.2 Two-Stage Borehole Test

The two-stage borehole hydraulic conductivity was developed by Boutwell (the test is sometimes called the Boutwell Test) and was under development as an ASTM standard at the time of this writing. The device is installed by drilling a hole (which is typically 100 to 150 mm in diameter), placing a casing in the hole, and sealing the annular space between the casing and borehole with grout as shown in Fig. 2.34. A series of falling head tests is performed and the hydraulic conductivity from this first stage (k_1) is computed. Stage one is complete when k_1 ceases to change significantly. The maximum vertical hydraulic conductivity may be computed by assuming that the vertical hydraulic conductivity is equal to k_1. However, the test may be continued for a second stage by removing the top of the casing and extending the hole below the casing as shown in Fig. 2.34. The casing is reassembled, the device is again filled with water, and falling head tests are performed to determine the hydraulic conductivity from stage two (k_2). Both horizontal and vertical hydraulic conductivity may be computed from the values of k_1 and k_2. Further details on methods of calculation are provided by Boutwell and Tsai (1992), although the reader is advised to refer to the ASTM standard when it becomes available.

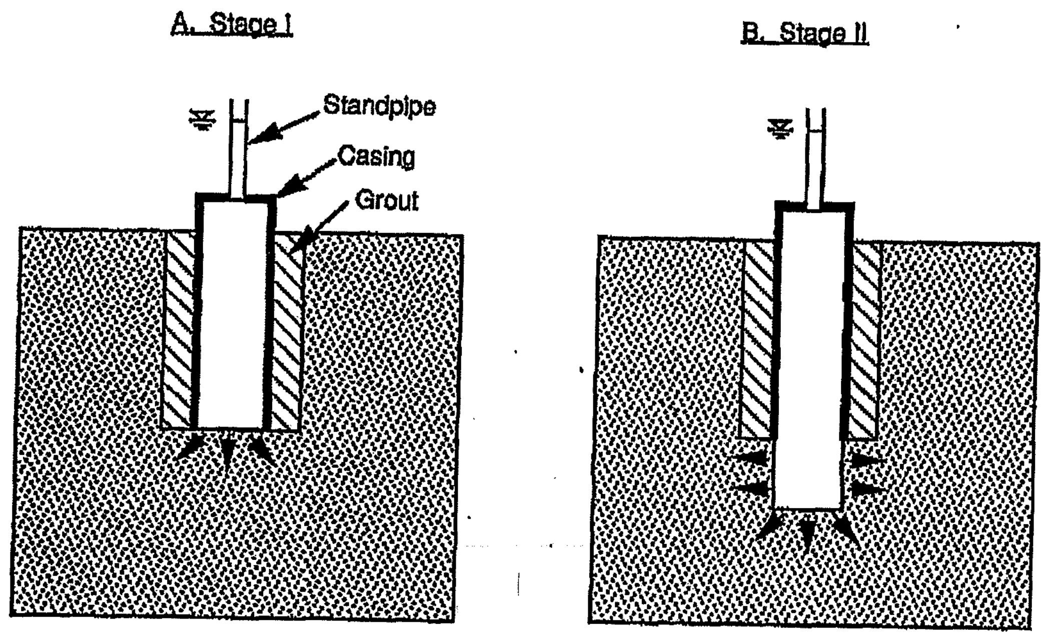


Figure 2.34 - Schematic Diagram of Two-Stage Borehole Test

The two-stage borehole test permeates a smaller volume of soil than the sealed double-ring infiltrometer. The required number of two-stage borehole tests for a test pad is a subject of current research. At the present time, it is recommended that at least 5 two-stage borehole tests be performed on a test pad if the two-stage test is used. If 5 two-stage borehole tests are performed, then one would expect that all five of the measured vertical hydraulic conductivities would be less than or equal to the required maximum hydraulic conductivity for the soil liner.

2.10.7.3 Other Field Tests

Several other methods of in situ hydraulic conductivity testing are available for soil liners. These methods include open infiltrometers, borehole tests with a constant water level in the borehole, porous probes, and air-entry permeameters. The methods are described by Daniel (1989) but are much less commonly used than the SDRI and two-stage borehole test.

2.10.7.4 Laboratory Tests

Laboratory hydraulic conductivity tests may be performed for two reasons:

1. If a very large sample of soil is taken from the field and permeated in the laboratory, the result may be representative of field-scale hydraulic conductivity. The question of how large the laboratory test specimen needs to be is currently a matter of research, but preliminary results indicate that a specimen with a diameter of approximately 300 mm (12 in.) may be sufficiently large (Benson et al., 1993).

2. If laboratory hydraulic conductivity tests are a required component of QA/QC for the actual liner, the same sampling and testing procedures are used for the test pad. Normally, undisturbed soil samples are obtained following the procedures outlined in ASTM D-1587, and soil test specimens with diameters of approximately 75 mm (3 in.) are permeated in flexible-wall permeameters in accordance with ASTM D-5084.

2.10.8 Documentation

A report should be prepared that describes all of the test results from the test pad. The test pad documentation provides a basis for comparison between test pad results and the CQA data developed on an actual construction project.

2.11 Final Approval

Upon completion of the soil liner, the soil liner should be accepted and approved by the CQA engineer prior to deployment or construction of the next overlying layer.

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ASTM D-1587, "Thin-Walled Tube Sampling of Soils"

ASTM D-2167, "Density and Unit Weight of Soil In Place by Rubber Balloon Method"

ASTM D-2216, "Laboratory Determination of Water (Moisture) Content of Soil and Rock"

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ASTM D-2488, "Description and Identification of Soils (Visual-Manual Procedure)"

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ASTM D-4944, "Field Determination of Water (Moisture) Content of Soil by Calcium Carbide Gas Pressure Tester Method"

ASTM D-4959, "Determination of Water (Moisture) Content of Soil by Direct Heating Method"

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LIST OF ACRONYMS

ASTM	-	American Society for Testing and Materials
CAFO	-	Confined Animal Feedlot Operations
CSL	-	Compacted Soil Liner
CQA	-	Construction Quality Assurance
DP	-	Discharge Permit
EMNRD	-	Energy, Minerals and Natural Resources Department
FML	-	Flexible Membrane Liner
GCL	-	Geosynthetic Clay Liner
GWQB	-	Ground Water Quality Bureau
HDPE	-	High Density Polyethylene
K_{sat}	-	Hydraulic Conductivity (i.e., permeability)
LUVD	-	Las Uvas Valley Dairies
MSW	-	Municipal Solid Waste
NMAC	-	New Mexico Administrative Code
NMED	-	New Mexico Environment Department
OCD	-	Oil Conservation Division
P.E.	-	Professional Engineer
PVC	-	Polyvinyl Chloride
SWB	-	Solid Waste Bureau
USDA	-	United States Department of Agriculture
USEPA	-	United States Environmental Protection Agency
UV	-	Ultraviolet Light (a component of sunlight)

STATE OF NEW MEXICO
BEFORE THE WATER QUALITY CONTROL COMMISSION

In the Matter of: **PROPOSED AMENDMENT** **TO 20.6.6 NMAC (Dairy Rule)**	**No. WQCC 13-08 (R)**

DIRECT TESTIMONY OF CHARLES W. FIEDLER, P.E., LEED AP

1.0 Experience and Qualifications

1.1. What is your name?

Charles W. Fiedler, P.E., LEED AP

1.2. Who is you employer?

Gordon Environmental, Inc.
Senior Project Director

1.3. Please describe your education and degrees.

Bachelor of Science in Civil Engineering from Texas A&M University (1978)
Master of Science in Civil Engineering from Texas A&M University (1982)

1.4. What professional licenses do you hold?

Professional Engineer-Texas (52247)
Professional Engineer-New Mexico (19731)

1.5. Please describe your experience related to your testimony.

My career began with the Texas Department of Health in their environmental health division where I was responsible for ground water system protection. In this position, I was responsible for monitoring public drinking water systems that primarily relied on ground water. Responsibilities included inspection of ground water well installations for ground water protection.

I subsequently was promoted into the solid waste group where my responsibilities included approving monitoring well installations, inspecting monitoring well installations, sampling and reviewing results from ground water monitoring well systems, and providing feedback confirming ground water sample compliance.

Since my first professional engagement, ground water monitoring has been an integral component of my career. The process of designing a ground water monitoring system has evolved from the days when wells were indiscriminately installed around a facility. Today, we routinely initiate a design process that evolved out of the requirements of the Resource Conservation and Recovery Act of 1976. In this design process, we conduct a hydrogeological investigation that includes exploratory borings to define the underlying geologic formations, including water-bearing zones proposed for monitoring. Through this process, we provide validation for the selected monitoring depths and locations based on site-specific data collected in the investigation, providing a higher quality monitoring well system, typically with an optimized number of wells.

1.6. Approximately how many monitoring well systems have you evaluated, designed and monitored?

Several hundred in a career span of 36 years. Just about every type of facility I have been involved with required some level of compliance monitoring and has included ground water monitoring wells to confirm the integrity of the operation.

1.7. For what types of facilities?

Primarily waste disposal facilities with containment structures such as disposal cells (associated with municipal solid waste, industrial waste, construction & demolition waste, exploration, production waste, hazardous waste, etc.) or containment basins (associated with waste water treatment, stormwater, septage, animal feedlot runoff, produced water, etc.).

1.8. Have you evaluated or designed monitoring well systems for dairies?

Yes, under both the old and new Rules.

1.9. What is the extent of your experience on projects requiring ground water discharge permits under the WQCC's Regulations?

I am routinely involved in the investigation and development of ground water monitoring systems associated with waste disposal facilities. My most recent project experience that required a ground water discharge permit was the permitting and modification of a septage dewatering facility where domestic septage is filtered to remove the solids in a bio-filter. The liquid is used to enhance green waste composting.

1.10. Have you designed any monitoring well systems required by the Dairy Rule, particularly 20.6.6.23NMAC?

No. I have developed and submitted several dairy discharge permits/renewals (for the Las Uvas Valley Dairy, DP-342, DP-946, DP-1265, & DP-1790), but none of these submissions proposed to install the significant number of additional wells this Rule *would require. The decision to oppose the prescriptive well placement required by the Rule was made based on the previous hydrogeological characterization that had been performed for these facilities. This characterization defined the depth to ground water, evaluated the demonstrated historical absence of evidence of ground water contamination, and relied on the findings of the geological and hydrogeological analysis that supported the fact that the existing ground water monitoring well system adequately represented and reported the ground water conditions at the facility.*

1.11. What is your experience in monitoring, evaluation, investigation, corrective action and abatement of ground water contamination in New Mexico?

I have significant experience monitoring ground water, from the collection of routine samples to the evaluation of the results; and I am familiar with the standard practices that are routinely implemented with various compliance monitoring programs. When our evaluation indicates that the results are not within the expected parameters, we actively investigate sampling methods and testing protocols to confirm that the results accurately reflect the true ground water condition. These investigations may include additional sampling and testing to confirm the original findings. Additional parameters may also be evaluated to isolate the source of the unexpected findings. Where the elevated readings are confirmed, we have undertaken corrective actions to identify the contamination source and implement abatement practices that rectify the contamination.

2.0 General Design Principles for Monitoring Well Systems

2.1. What technical principles are generally relied upon to design a proper ground water monitoring system under the Commission's general discharge permit regulations or similar regulations?

The technical principles that are generally relied upon to design a proper ground water monitoring system typically start with the characterization of the geological and hydrogeological settings that lead to the site-specific definition of gradient (i.e., the slope of the ground water surface elevation, see ***Fiedler – 1****), and the placement of monitoring wells relative to the gradient and the units being monitored. These principals are detailed in a vast array of technical resources including the* ***RCRA Ground-Water Monitoring Draft Technical Guidance*** *issued by the Environmental Protection Agency, Office of Solid Waste in November 1992. This document outlines the basic principles that are typically relied upon in the development of a ground water monitoring system:*

- *Conduct a Hydrogeologic Investigation*
  - *Define the regulatory requirements and technical objectives*
  - *Conduct the preliminary investigation*
  - *Develop the initial conceptual model (Basis of the field investigation)*
  - *Conduct the field investigation*
  - *Refine the conceptual model based on the field findings*
  - *Conduct additional investigation(s) as necessary to adequately refine the conceptual model*

- *Design the ground water monitoring system based on the hydrogeological investigation*

2.2. Are there standard guidance and technical reference documents utilized by professionals who design ground water monitoring systems?

Yes. (See ***Fiedler – 3****). The* ***RCRA Ground-Water Monitoring Technical Enforcement Guidance Document*** *published by the Environmental Protection Agency (EPA), Office of Solid Waste Programs Enforcement in September 1986 represents the original basis for most ground water monitoring system designs undertaken today. This document outlines the process typically used to define ground water at a particular location and outlines the methodology for positioning the upgradient (i.e., the shallowest ground water surface elevation in the study) and downgradient (i.e., deeper ground water surface elevations) monitoring points. (See* ***Fiedler – 1****). Subsequently, these principles were expanded upon in the* ***RCRA Ground-Water Monitoring Draft Technical Guidance*** *issued by the EPA, Office of Solid Waste in November 1992. This document details the basic principles that are typically relied upon in the development of a ground water monitoring system as follows:*

- *Conduct a Hydrogeologic Investigation*
  - *Define the regulatory requirements and technical objectives*
  - *Conduct the preliminary investigation*
  - *Develop the initial conceptual model (Basis of the field investigation)*
  - *Conduct the field investigation*
  - *Refine the conceptual model based on the field findings*
  - *Conduct additional investigation(s) as necessary to adequately refine the conceptual model*
- *Design the ground water monitoring system based on the hydrogeological investigation*

2.3. What site-specific information is utilized by a professional in the design of a monitoring well system?

Professional Engineers and geologists with specific training in hydrogeology are typically relied upon for their technical expertise in the design of monitoring well systems. Often these professionals will work together on a ground water monitoring system design. While DIGCE does not have a position on who is qualified to perform the hydrogeological evaluations, they understand that the Department may accept work from Engineers or hydrogeologists. Therefore, I will refer to these professionals as "qualified professionals." Typically, for a planned new facility, the qualified professional will perform a preliminary investigation that is initiated with the collection of available regional information relating to the geology and hydrogeological setting of the particular site and its surrounding area. Reviewing previous studies that assess the site-specific nature of the ground water setting represents the first step in understanding the ground water regime at a particular location. The studies may include field investigations of previous explorations in the vicinity, providing insight into the ground water *hydrogeology of an area. Some of this information is requested by NMED in 20.6.6.20(X) NMAC, which requires the identification of water wells within one mile of the facility.*

The qualified professional will undertake the second step by focusing on data that is relevant to the specific location of interest and outline a conceptual model of the geology and hydrogeology with which to develop a preliminary subsurface investigation plan. The investigation plan typically consists of a minimum of three geotechnical borings, which may be existing borings or well logs in close proximity to the dairy facility, used to define the ground water gradient at a particular location.

The third step in this process is to initiate a site-specific investigation with geotechnical borings based on the conceptual model. This investigation will be used to develop and collect geological and hydrogeological information from field observations of the borings. In some instances, laboratory testing of boring samples may be analyzed to provide additional insights regarding the geology and utilized to correlate the site-specific findings from this investigation to the regional information compiled in the first step.

The final step is to use the field data collected to refine the conceptual model to reflect the observed conditions. With this refined model, the qualified professional can define the basis for upgradient and downgradient monitoring; identifying the most appropriate location for monitoring wells that will confirm the absence (or presence) of contamination from the proposed facility. Based on this investigation, installation of the monitoring well system may be completed.

2.4. How much site-specific information is typically obtained and utilized for the design of a monitoring well system?

As with any technical investigation, determining how much site-specific technical information is required can be a challenging question. Typically, the collection of regional geologic and hydrogeologic information will provide a good assessment of the ground water regime for a particular location. Based on this information, a conceptual model can be defined that provides the basis for a site-specific investigation. Ideally, the completion and analysis of at least three geotechnical borings, or use of information from existing borings in the area, will confirm the regional geologic setting and provide a basis for the facility ground water monitoring plan. Depending on the complexity of the geological setting and the size of study area being evaluated, additional geotechnical borings may be required to define the geologic setting more accurately.

2.5. Are there any differences with respect to dairies that should be considered in the design of a monitoring well system?

No. While no two dairies will possess the same hydrogeologic setting, the process to characterize them, defining gradient and depth to the most-shallow ground water, are the same for all locations. Once a hydrogeologic evaluation has been completed, the monitoring systems will only differ in the number and spatial layout of the wells required *to monitor the facility appropriately. I should note that my testimony in this section is primarily focused upon planning and permitting a new facility. Later in this testimony I discuss how the rule should address existing dairies that have been permitted and have an approved monitoring well system under previously-issued discharge permit.*

2.6. What are the typical costs for monitoring wells based upon the design requirements in the dairy rule? How do the costs vary depending on site-specific factors?

Installation and development of a typical monitoring well (per 20.6.6.23(D) NMAC, which references 19.27.4 NMAC) will average approximately $150 per foot of well depth. The required depth of the well to reach the first relevant water-bearing zone is the primary determinant in the final cost of the well (i.e., the deeper you have to go to get to water the more expensive the well). Additionally, diverse geology will also have an impact on the installation cost. A diverse geological and hydrogeological setting may require additional wells to monitor the facility location adequately. (See DIGCE Ground Water Monitoring Presentation to NMED Staff Slide 9 dated 05/16/2014 included as ***Fiedler - 2****). The cost is also affected by the well drilling method required (e.g., hollow stem auger, air rotary, mud rotary, etc.) for the materials encountered (i.e., sand, clay, gravel, rock, etc.).*

The current cost to plug an existing ground water monitoring well is approximately $20 per foot or $2,000 for a 100 foot deep well. Quarterly ground water monitoring (i.e., sampling, analysis and reporting) will cost an additional $3,000 per well per event.

3.0 Current Dairy Rule Requirements

3.1. What problems have been identified with the current ground water monitoring requirements of the Dairy Rule (20.6.6.23 NMAC)?

The prescriptive nature of the current Dairy Rule will require any Permittee that can comply with the monitor well location requirements to request a variance from the Commission. The variance process (20.6.2.1210 NMAC) requires the Permittee to petition the Commission for relief from the prescriptive requirements of the Dairy Rule ground water monitoring requirements. Given the prescriptive nature of this Rule, it is anticipated that almost every dairy seeking a permit will be required to come before the Commission for a variance from some component of the ground water requirements. The ramifications of the Commission hearing and ruling on over 100 variance requests in every dairy permitting cycle will potentially represents a burden beyond the logistical capability available.

The ground water monitoring well location requirements (20.3.3.23(A) NMAC) mandating an installation zone around potential contamination sources (i.e., stormwater/waste water lagoons, application fields, etc.) represent a significant flaw in the potential design of an effective ground water monitoring system. This requirement only considers ground water gradient when determining the monitoring well location (i.e., downgradient). There is no recognition that the hydrogeology of the facility might *dictate a location that provide more accurate monitoring of the ground water passing under the potential contamination source.*

3.2. What is the stated purpose of the ground water monitoring requirements in 20.6.6.23(A) NMAC?

To monitor ground water quality hydrologically downgradient of each potential source of ground water contamination. The existing Dairy Rule establishes the requirement for downgradient wells to detect exceedances of the ground water quality standards relative to the upgradient (benchmark) water quality.

3.3. Is this purpose consistent with the purpose of ground water monitoring under other federal and New Mexico environmental laws?

Yes. It is standard practice in both Federal and other State Rules to compare ground water quality both to the upgradient (benchmark) water quality, as well as the established ground water quality standards.

3.4. How does it compare to the provisions of the Commission's general discharge permit regulations, particularly 20.6.2.3107 NMAC?

The Commission's general discharge permit requirements relating to Monitoring, Reporting and Other Requirements (20.6.2.3107 NMAC) are simplistic in their outline of the ground water monitoring infrastructure that is detailed in Section 2, which requires "The installation, use, and maintenance of monitoring devices for the ground water most likely to be affected by the discharge." This leaves the definition of how and where the monitoring wells are installed to the discretion of the Permittee, although more recent experience under the general rules was that the Department often sought to change or add to the monitoring requirements through discharge permit conditions. In comparison, the requirements of 20.6.6.23 NMAC are specific regarding the potential contamination sources that must be monitored; the specific distance within which the monitoring wells must be placed from the potential contamination source; and the mandate to install a monitoring well for a prescribed number of acres utilized for specific land application practices. Unfortunately, the arbitrary nature of the Dairy Rule in §23 does not address the variability of hydrogeologic settings when it prescribes the monitoring well locations relative to potential contamination sources. In comparison, the general discharge permit requirements provide appropriate discretion to the Permittee, while the current Dairy Rule essentially provides no discretion regarding monitoring well placement.

3.5. How is the number of required monitoring wells determined under the Dairy Rule for wastewater impoundments? Storm water impoundments? For land application areas? For a dairy facility in general?

- *Wastewater Impoundments: Rule 20.6.6.23(A)(1) NMAC requires a minimum of one monitoring well downgradient, within **75 feet** of the top inside edge of each impoundment.*

- *Storm Water Impoundment:* *Rule 20.6.6.23(A)(3) NMAC requires a minimum of one monitoring well downgradient, within* ***75 feet*** *of the top inside edge of each impoundment.*
- *Land Application Areas:* *Rule 20.6.6.23(A)(4) NMAC requires ground water monitoring (at least one monitoring well) downgradient and within* ***50 feet*** *of each 40 acre flood irrigated field (or portion) and within* ***50 feet*** *of each 160 acre sprinkler or drip irrigated field (or portion).*

Fielder – 2 *provides a graphical example of the requirements for monitoring well locations. These prescriptive setbacks are entirely arbitrary and without technical foundation and can be impossible to attain in certain circumstances.*

3.6. How does this approach to determine the number of monitoring wells compare to the approaches typically used for other types of facilities?

The approach prescribed in Rule 20.6.6.23(A) looks only at one aspect of the hydrogeological setting, the ground water gradient. It ignores the potential geology that might render the prescribed system ineffective in detecting a trend toward exceedance of the ground water standards at the earliest possible occurrence. In addition, this excessively prescriptive Rule has defined a default design that does not account for site-specific conditions that might render the monitoring well locations and layout relative to the potential contamination sources dysfunctional.

Almost without exception, the general regulatory basis for design of ground water monitoring systems relies on the professional characterization of the subsurface geology and hydrogeology to establish the most effective monitoring well layout. Considering that, for the rest of the discharges managed by the NMED Ground Water Quality Bureau, it is sufficient to identify the wells to be used for monitoring (per 20.6.2.3106 NMAC). This raises the obvious question... "Why is the potential for contamination from a Dairy more stringently controlled than potential discharges from a solid waste unit, a hazardous waste unit, a waste water lagoon, or a leaking underground tank?"

3.7. Are the regulations governing the number of monitoring wells required for other types of facilities typically as prescriptive?

No. The generally accepted basis for ground water monitoring system design began with the implementation of RCRA and the guidance documents developed in support of the implementation of the Federal regulations that were established. These guidance documents outlined a methodology that relies significantly on the hydrogeological characterization of a facility (i.e., compile regional hydrogeologic model for the facility, define a conceptual hydrogeologic model of the facility, develop and implement a site investigation with borings, refine the hydrogeologic model, design a ground water monitoring system, implement the system design). This approach represents the basis for ground water monitoring system design for the regulatory programs identified below:

- *Per 20.9.9.9 NMAC, NMED Municipal Solid Waste facilities require that..."A ground water monitoring system shall consist of a sufficient number of wells,*

installed at appropriate locations and depths, to yield ground water samples from the uppermost aquifer that:
(1) represent the background quality of ground water that has not been affected by a release from the landfill as determined under 20.9.9.10 NMAC; and
(2) represent the quality of ground water passing the detection monitoring point which shall be at the waste management unit boundaries on land owned by the owner of the Landfill... ".

- *NMED Hazardous Waste facilities require compliance with Federal regulations (per 20.4.1.500 NMAC) set forth in 40 CFR Part 264 which require the following in Subpart 97(a) relating to general ground water monitoring requirements:*
  (a) The ground-water monitoring system must consist of a sufficient number of wells, installed at appropriate locations and depths to yield ground-water samples from the uppermost aquifer that:
  - *(1) Represent the quality of background ground water that has not been affected by leakage from a regulated unit;*

- *NMEMNRD Oil Conservation facilities require (per 19.15.36.17.A NMAC)... "An Engineering Design Plan that includes a hydrogeologic report that provides sufficient information and detail on the site's .....ground water hydrology to enable the division to evaluate the actual and potential effects on ... ground water".*

3.8. Describe how the locations of monitoring wells are determined under the current dairy rule for impoundments and land application areas.

The Rule, 20.6.6.23(A) NMAC, arbitrarily dictates a horizontal distance downgradient of the edge of a potential contamination source (i.e., lagoon, pond, land application field, etc.) within which the monitoring well must be installed. This methodology does not take into consideration the site geology or other characteristics of the local hydrogeology, significantly impacting the ability of the prescribed wells to provide the detection levels required by this section. The prescriptive design arbitrarily assumes that all hydrogeologic conditions can be adequately monitored by a well located within 75 feet downgradient of the edge of a potential contamination source. There is no guarantee that this prescription for monitoring well location will provide the optimal installation to detect an exceedance when the hydrogeology of a location is not considered.

3.9. Are the regulations governing the locations of monitoring wells required for other types of facilities typically as prescriptive?

No. The EPA, in their ***RCRA Ground-Water Monitoring Technical Enforcement Guide (September 1986)****, probably stated it best when they proclaimed... "****clearly, the spectrum of hydrogeologic regimes is great, and no single document could provide detailed, step-by-step instructions for monitoring each one****" when referring to solid waste disposal facilities. This statement also holds true for the diaries regulated by NMED and emphasizes the recognition by the regulating community that there is no prescriptive design that will be applicable to all circumstances.*

3.10. How is information from ground water monitoring used under the contingency provisions for impoundments under the Dairy Rule? [refer to 20.6.6.27 (B)]

20.6.6.27 NMAC requires that ground water sample results from downgradient wells provide the basis for comparison with samples from the upgradient well(s) and the ground water standards (20.6.2.3103 NMAC). Comparing the downgradient sample results to the upgradient sample results provides a site-specific comparison of ground water quality under the facility; and comparing these results to the ground water standards provides a comparison to the level at which the water is considered contaminated. This approach forms the basis for evaluation of all ground water monitoring programs and is applicable to the ground water monitoring results from dairies. DIGCE accepts this as the standard for ground water monitoring analysis.

3.11. In your experience, to what degree can the results of monitoring from a single monitoring well be used to conclusively determine whether a particular impoundment has excessive seepage such that corrective action or replacement is necessary?

Sample results from a single monitoring well are of limited value without the determination of gradient (i.e., the elevation of the ground water surface at one point under the facility relative to the ground water surface elevation at another point, ***Figure*** *1). Without a second ground water monitoring point to compare water surface elevations the relative gradient under the facility cannot be defined. The ground water gradient under the facility is a critical component of the ground water evaluation process relative to the monitored unit. The availability of sample results from a second monitoring well in the opposite gradient from the evaluated well allows for comparison of sample results and a determination of water quality variation (i.e., exceedances). At a minimum, the sample results from one ground water monitoring well can be compared to the regulatory standards for a determination of compliance. However, if this sample is from an upgradient well, the results reveal nothing regarding the potential impacts to ground water quality from a facility.*

3.12. Would your conclusion be any different for different types of liner systems utilized for the impoundment?

No. A leaking liner is a leaking liner. The characteristic ground water quality constituents evaluated are the same, irrelevant of the type of liner utilized. Ground water sample monitoring results are not dependent on the type of liner providing containment for a particular unit.

<u>4.0 DIGCE Proposed Amendments</u>

4.1. What amendments would be required in the current Dairy Rule to establish requirements that define a functional ground water monitoring system?

The current Dairy Rule will need to be amended to provide sufficient flexibility in the location and installation of ground water monitoring wells. The Permittee, based on the hydrogeological characterization, should have the flexibility to locate the ground water monitoring wells appropriately. The installation of a monitoring well should not be limited by a prescriptive standard that arbitrarily defines the well location based solely on distance and gradient. It should provide flexibility that also considers the hydrogeology of a location and provide the flexibility to locate the monitoring well where it will provide the most representative evaluation of ground water flowing under the dairy facility. This flexibility should be provided in the Rule, without the requirement to seek a variance from this Commission for every monitoring location that does not fit the prescription within the current Rule.

4.2. Turning to DIGCE's Petition, Attachment A, on page 24, please explain the reason for deleting "hydrologically downgradient of each source of ground water contamination: wastewater, stormwater, and combination wastewater/stormwater impoundments, and fields within the land application area" and replacing it with "at the dairy facility with at least one hydrologically upgradient and two hydrologically downgradient wells."

The Petition focuses on providing a ground water monitoring system that requires the Permittee (supported by the services of a qualified professional familiar with the geotechnical and hydrogeological characteristics of the area) to evaluate the geologic and hydrological setting in order to design an efficient monitoring well layout that captures the necessary information to evaluate accurately the ground water condition downgradient from the potential contamination sources. By prescribing the well location distance from the monitored feature, the Rule limits the flexibility of the Permittee to rely on the site-specific hydrogeologic information available for the optimal placement of the monitoring well, without the requirement for a variance. The current Rule (20.6.6.23 NMAC) provides a prescriptive formula that requires a Permittee ostensibly to install a ground water monitoring system without developing an understanding of the hydrogeology of the site. It should be noted that a prescriptive monitoring system installation under this Rule could have the adverse effect of not accurately identifying the exceedances that may be present as a result of the inappropriate positioning of monitoring wells.

The current Dairy Rule ignores the accepted principles and practices established by the EPA (originally outlined in the ***RCRA Ground-Water Monitoring Technical Enforcement Guide, September 1986****, and expanded upon in the* ***RCRA Ground-Water Monitoring Draft Technical Guidance, November 1992****) by prescribing an arbitrary approach to ground water monitoring. Both the Solid Waste Bureau and the Hazardous Waste Bureau at NMED, as well as other state agencies (i.e., New Mexico Energy, Minerals and Natural Resources), have embraced the EPA guidance incorporating the accepted and proven approach that results in a ground water monitoring system that provides accurate and reliable results for the life of the facility. The regulatory approach to ground water monitoring outlined in 20.6.6.23 NMAC is flawed by failing to outline the basic requirement to characterize the ground water hydrogeology of the location. Without this information, a ground water gradient cannot be defined. Without a physical* *definition of gradient at the facility, none of the rest of this section of the Rule makes any sense. Ultimately, the Rule, as implemented, potentially exposes the regulated facility to a false sense of environmental security by installing a ground water monitoring system that does not necessarily address the site-specific hydrogeology present at the facility location.*

4.3. What is the basis for requiring at least one hydrologically upgradient and two hydrologically downgradient wells?

A hydrologically upgradient ground water monitoring well provides the background or benchmark for the quality of the ground water passing under the regulated facility. This typically represents the minimum number of wells that will be required to characterize properly the ground water hydrogeology for a typical dairy. The requirement for an upgradient ground water monitoring well represents no change from the current Rule (20.6.6.23(A)(5) NMAC).

The Rule proposed by DIGCE would allow the regulated facility the flexibility to rely on the ground water hydrogeological characterization, typically conducted to identify the appropriate number of downgradient ground water monitoring wells (minimum two) to provide spatial coverage for the potential contamination sources. Instead, the current Rule (20.6.6.23(A)(1, 2, 3, & 4) NMAC) prescriptively details the precise distance from the inside edge of the contamination source, and defines the number of monitoring wells per potential contamination source or acreage of land application field. This prescription does not take into account the total characterization of the hydrogeology that might identify monitoring well locations better suited to monitor the geology under the facility. By following the prescriptive requirements of the Rule, the facility owner may inadvertently place the monitoring well in a downgradient location that does not intercept the downgradient ground water flowing under the potential contamination source, providing a false sense of security and not fulfilling the intention of the Rule to..."detect an exceedance or a trend toward exceedance of the ground water standards...". Without flexibility in the Rule regarding the placement of ground water monitoring wells, a Permittee is forced to seek a variance from the Commission to rely on the detailed information available in a hydrogeological characterization to design an optimal ground water monitoring system.

The current Rule ignores critical information available from a hydrogeological evaluation. Instead, this Rule relies on a prescriptive, "easy to follow, easy to permit" approach to ground water monitoring system design that assumes the optimal location for all monitoring wells will be within a prescribed distance from the monitored unit (i.e., 75 feet from a wastewater lagoon). Unfortunately, this approach will result in the inappropriate placement of monitoring wells and a false sense of environmental security. The only relief from this prescriptive placement requirement is for the Permittee to seek a variance from this Commission. The required variance would allow a Permittee to undertake the optimal placement of ground water monitoring wells based on a hydrogeological characterization. Considering that just about every dairy will have ground water monitoring well locations that require a variance, this Commission will *constantly face variance requests that could be avoided by providing flexibility within this Rule. It is for this reason that DIGCE requests the revision of this Rule.*

4.4. Under this language, would it ever be necessary to have more than one hydrologically upgradient well? Under what types of circumstances?

Yes. Based on a ground water characterization, circumstances in the hydrogeology of the area may identify upgradient ground water conditions that require more than one upgradient monitoring well to represent adequately the quality of more than one source of ground water. The objective of ground water monitoring is to compare the upgradient and downgradient ground water from the same source to determine if the facility has impacted water quality as it flows underneath. If the upgradient source is not the same source supplying water to the downgradient monitoring well, there may be naturally occurring differences in quality from the various source that would be interpreted as contamination when none may be present.

4.5. Under this language, would it ever be necessary to have more than two hydrologically downgradient wells? Under what types of circumstances?

Yes. Given a facility's size and the distribution of potential contamination sources within the facility, it may be necessary to have more monitoring wells to monitor adequately various downgradient locations when the potential contamination sources are separated; and potential migration pathways from these potential contamination sources cannot be adequately monitored by only two wells.

4.6. How would the necessary number of monitoring wells be established under the rule if the Commission adopts the proposed amendment?

A professional qualified in the characterization of ground water hydrogeology and the design of ground water monitoring systems, would be engaged to evaluate the geological and hydrogeological setting of the facility to determine the upper-most aquifer and ground water gradient at the facility. Based on this information and the existing or proposed facility potential contamination sources, the qualified professional would develop a ground water investigation plan that would consist of at least three geotechnical borings extending to a depth where ground water is anticipated. Based on the depth at which ground water is encountered, the qualified professional would define the ground water gradient, thereby identifying the proper locations and numbers of upgradient monitoring wells and downgradient monitoring wells required to provide adequate monitoring coverage for potential contamination sources within the facility.

4.7. What is the reason for the addition of the language "in a location that is protective of the well" to 20.6.6.23(A) NMAC?

The physical location of a monitoring well is critical to ensure the well is situated where it is protected from damage by facility operations; and is not subject to inundation from flooding or irrigation. Identifying this secure location is a critical component of the *qualified professional's responsibility in the design and development of the ground water monitoring well system. Having the flexibility, under the Rule, to place the monitoring well in a secure location, without having to request a variance from the Commission is crucial.*

4.8. What are the reasons to strike the first sentences of the current 20.6.6.23(A)(1), (2) and (3) NMAC?

Establishing an arbitrary distance (i.e., 75 feet) within which a ground water monitoring well must be installed will require the inappropriate installation of monitoring wells. Examples may include installation on a levee between two lagoons, on a levee side slope, within a drainage feature, in a roadway, etc. In addition, the 75-foot setback may not be a sufficient distance to address geological features where a deep water table, combined with interbedded materials deposited in horizontal layers, could divert a potential discharge from the potential contamination source across the monitoring well and above the screened interval, thereby rendering the monitoring well useless.

4.9. Do you know any scientific basis for a 75 foot maximum distance as specified in 20.6.6.23(A)(1)? Any basis in other regulations or guidance?

No. While there is guidance to minimize the separation distance between a monitoring well and the potential contamination source, none of the regulatory guidance reviewed prescribes a minimum distance from a potential contamination source to the monitoring well installation. The required practice in other regulations and guidance is to defer to the qualified professional, relying on their expertise and knowledge of the geologic and hydrogeologic settings. The qualified professional acquires their knowledge by conducting a characterization to determine the appropriate location and spacing of the monitoring well from the potential source of contamination (RCRA Ground-Water Monitoring Draft Technical Guidance, November 1992). Without relying on this level of information (i.e., deferring exclusively to a prescriptive 75-foot maximum distance down gradient), the Permittee is handicapped to install an optimal ground water monitoring system without a variance.

4.10. What are the reasons to strike the second sentences of the current 20.6.6.23(A)(1), (2) and (3) NMAC?

The second sentence in §(A)(1), (2), and (3) applies the requirement for existing facilities, and would require the Permittee to relocate existing wells and/or install new monitoring wells within 75 feet of the identified potential contamination source (i.e., wastewater, combination wastewater/stormwater, or stormwater impoundments). DIGCE proposes to strike this section because it would negate previous monitoring system approvals, even if an existing system was still functioning properly; and providing quality, representative results. In addition, this requirement would mandate the installation of additional monitoring wells for the identified potential contamination sources without any site-specific characterization confirming that the relocated or new monitoring wells would provide additional beneficial (quality) information. This Rule is being implemented even *though the existing, previously approved ground water monitoring system may already provide quality monitoring. In addition, without this revision, the Commission would be required to evaluate variance requests for any monitoring well that could not be situated within the 75-foot perimeter of potential contamination sources.*

4.11. What are the reasons to strike subparagraph (c) of 20.6.6.23(A)(1) and 20.6.6.23(A)(2) and (3) NMAC relating to monitoring well installation?

The proposed DIGCE revisions to §(A)(1-3) address the minimum number of ground water monitoring wells and the timeframe in which new wells monitoring a dairy facility must be installed. The proposed revision of requirement in §(A)(1-3) negates the need to repeat the requirement in §(A)(1)(c), §(A)(2) and §(A)(3).

4.12. What are the reasons to strike 20.6.6.23(A)(4)(a) and (b) NMAC?

The requirements of § (A)(4)(a) and (b) relating to the installations of monitoring wells based on the number of acres subject to land application of effluent is being struck based on the absence of an apparent nexus between the acreage per well and the geologic or hydrologic setting There is no identifiable relationship between the potential impact from the land application of wastewater and the number of monitoring wells required when the ground water hydrogeology is not taken into consideration. The number of acres in the land application footprint has virtually no impact on the potential for contamination. The current approach will result in the installation of monitoring wells in locations where their positioning may not be prudent from an operational perspective (i.e., within fields, roads, drainage features, etc.). Their presence in these locations provide no significant improvement in facility compliance monitoring over monitoring wells situated along the downgradient dairy facility perimeter. A hydrological characterization should be completed for the facility prior to determining the appropriate location for the ground water monitoring wells.

4.13. Do you know of any scientific basis for the 40 acre provision for flood irrigated fields as specified in 20.6.6.23(A)(4)(a)? For the 50 foot provision in the same subparagraph? For the 160 acre provision in 20.6.6.23(A)(4)(b)?

No. There appears to be no technical basis for locating ground water monitoring wells within 50 feet of every 40 acres of flood irrigated fields; or within 50 feet of every 160 acres of sprinkler/drip irrigated fields. Arbitrarily prescribing a downgradient distance within which all ground water monitoring must be accomplished represents a problem because no prescribed distance will work for every hydrogeologic setting Relying on a hydrogeologic characterization to locate the ground water monitoring well locations properly is the accepted practice and will result in an optimal ground water monitoring system. This is the reason DIGCE has proposed deleting this section of the current Rule.

4.14. What are the reasons to strike 20.6.6.23(A)(4)(c) NMAC?

Once again, there appears to be no technical basis for locating ground water monitoring wells downgradient from a field when grazing is used in lieu of mechanical harvesting. The concern appears to be that livestock consuming a crop directly from the field (i.e., grazing) will result in a greater potential for contamination when compared to harvesting the crop with machines and feeding it to the livestock in pens. There does not appear to be a significant potential contamination source here that requires monitoring, raising the question why this type of field would even require monitoring. In addition, there does not appear to be any significant benefit to this level of monitoring that would not be addressed by a ground water monitoring system design based on a hydrogeological characterization. This approach would identify the optimal location for ground water monitoring well placement. DIGCE proposes to strike the requirement §(A)(4)(c) and rely on a hydrogeologic characterization to locate properly the ground water monitoring well locations.

4.15. What are the reasons to strike 20.6.6.23(A)(5) NMAC?

The requirement §(A)(5) to install an upgradient well is being struck as redundent of the requirements proposed by DIGCE in the proposed revisions to §(A) relating to dairy facility monitoring.

4.16. What are the reasons for the amendments to 20.6.6.23(A)(6) NMAC?

The DIGCE proposed amendments to §(A)(6) are designed to allow an existing permitted facility the ability to continue to use a previously approved ground water monitoring system that is currently in place and providing quality results for a dairy reporting compliance with the ground water standards. As a result of these proposed amendments, the remaining requirements of this Subparagraph are deleted because they are no longer applicable to existing ground water monitoring systems.

4.17. Will NMED ever be able to require replacement of an existing monitoring well that is not effectively monitoring ground water as intended if the Commission decides to amend 20.6.6.23(A)(6) NMAC as proposed in the petition,?

Yes. NMED retains the right to address the effectiveness of a ground water monitoring system through the provisions of 20.6.6.27 NMAC. Allowing for the continued use of previously approved ground water monitoring wells that continue to provide representative ground water monitoring (as proposed by DIGCE in 20.6.6.23(A)(6) NMAC), even though a well may not meet every requirement of the current Rule, has technical merit. The historical record established by an existing well is invaluable to the understanding of the ground water hydrogeology. Replacing an existing well in the same location requires the re-establishment of ground water quality parameters for this location, given the fact that no two monitoring points will provide identical results no matter how close they are physically located. In addition, the financial burden for the dairy to decommission (i.e., plug) a typical 100 foot existing well at an average cost of

$2,000 and install/develop a new well at an average cost of $15,000 is a concern. The effectiveness of the ground water monitoring system remains subject to the provisions of 20.6.6.27(C) NMAC which specifically allows for the replacement of a ground water monitoring well if it is determined that the identified well is not effectively monitoring ground water as intended. NMED retains the necessary authority to address any concerns that may arise regarding the continued use of an existing well.

4.18. What are the reasons for the proposed amendments to 20.6.6.23(A)(7) NMAC?

The DIGCE proposed amendment to §(A)(7) continues to reinforce the reliance on a hydrogeologic characterization. DIGCE once again proposes developing a ground water monitoring system that relies on the optimum location for monitoring wells for the entire dairy facility rather than prescriptively monitoring each potential contamination source.

4.19. What are the reasons to strike 20.6.6.23(A)(7)(c) NMAC?

DIGCE concurs with the desired goal to reduce the number of duplicate sample results and the associated sampling, analysis and monitoring costs of approximately $3,000 per well, per event. By relying on a hydrogeologic characterization, DIGCE once again proposes developing a ground water monitoring system that identifies the optimum location for monitoring wells. The requirements of §(A)(7)(c) that established ground water monitoring criteria exempting adjacent or adjacent groupings of contiguous sprinkler or drip irrigated fields are struck because they are redundant. The DIGCE proposed revisions to §(A) relating to dairy facility monitoring based on the findings of a hydrogeologic characterization will provide better definition for the appropriate location of ground water monitoring wells.

4.20. What are the reasons to strike 20.6.6.23(A)(8) NMAC?

The requirements of §(A)(8) providing for a third downgradient monitoring well are struck because they are duplicative of the requirements in the DIGCE proposed revisions to §(A) relating to dairy facility ground water monitoring and which requires at least two hydraulically downgradient wells. Once again, the DIGCE proposed revisions to §(A) relating to dairy facility monitoring based on the findings of a hydrogeologic characterization will provide better definition for the appropriate location of ground water monitoring wells.

4.21. If the Commission accepts the proposed amendments to delete the prescriptive requirements for monitoring well locations, how will locations be determined and proposed under 20.6.6.23(B) NMAC?

A professional, qualified in the study of ground water hydrogeology and design of monitoring systems, would be engaged to evaluate and characterize the geological and hydrogeological setting of the facility to determine the upper-most aquifer and ground water gradient at the facility. Based on this information and the potential contamination *sources on an existing or proposed facility, the qualified professional would develop a ground water investigation plan that would consist of at least three geotechnical borings extending to a depth where ground water is anticipated and a confining bottom formation is identified. Based on the depth at which ground water is encountered, the qualified professional would define the ground water gradient and identify the upgradient and downgradient ground water monitoring well locations required to provide the facility with optimal monitoring coverage for potential contamination sources within the facility.*

4.22. What are the reasons for the proposed amendment to 20.6.6.23(B)(1) NMAC?

The proposed amendment revises §(B)(1) to strike the specific reference to "contamination source", and replace it with "dairy facility" to be consistent with the monitoring description presented in the proposed amendment of §(A). This proposed change also reflects the DIGCE philosophy that the development of a hydrogeologic characterization of the facility location represents the optimum basis for the ground water monitoring system proposed.

4.23. What are the reasons to amend the heading to 20.6.6.23(D) NMAC?

The DIGCE proposed heading for §(D) is revised to focus the section on "new monitoring wells", when identifying the applicability of this section. DIGCE concurs that all "new" monitoring wells should meet this standard. With this proposed amendment, DIGCE rejects the position that existing, previously approved monitoring wells that are effectively monitoring ground water at a facility should be replaced if they do not meet this standard. In addition, the financial burden for the dairy to decommission (i.e., plug) a typical 100 foot existing well at an average cost of $2,000 and install/develop a new well at an average cost of $15,000 is a concern. The effectiveness of the ground water monitoring system remains subject to the provisions of 20.6.6.27(C) NMAC which specifically allows for the replacement of a ground water monitoring well if it is determined that the identified well is not effectively monitoring ground water as intended. NMED retains the necessary authority to address any concerns that may arise regarding the continued use of an existing well.

4.24. What are the reasons to amend 20.6.6.23(H)(3) NMAC?

The proposed DIGCE amendment to §(H)(3) provides the department with the flexibility to grant an extension of time for a Permittee to develop and deliver the monitoring well survey report when good cause for the delay is provided.

4.25. What are the reasons to amend 20.6.6.23(I) NMAC?

The DIGCE proposed amendment to §(I) adds the requirement to provide State Plane coordinates to define more accurately the ground water monitoring well locations.

4.26. What are the reasons to amend 20.6.6.23(K) NMAC?

The DIGCE proposed amendment to §(K) provides the department with the flexibility to grant an extension of time for a Permittee to develop and deliver the monitoring well survey report when good cause for the delay is provided.

4.27. What are the reasons to strike 20.6.6.23(M) NMAC?

The DIGCE proposal to strike §(M) questions why this type of guidance for an optional procedure would be codified within the Rule. Considering the limited value of the information derived from this requirement to perform downhole inspections of ground water monitoring wells, including this level of prescriptive guidance within the Rule is unnecessary. This type of information is more appropriately provided in department guidance documents.

4.28. What are the benefits of the overall amendments to 20.6.6.23 NMAC as proposed by DIGCE?

The benefits of the DIGCE proposed amendments to 20.6.6.23 NMAC relate primarily to providing the Permittee with the ability to develop a ground water monitoring system for the dairy facility that optimizes the ability to evaluate ground water conditions on a site–specific basis. Under the prescriptive constraints of the current Rule, this goal is unachievable. The ability to optimize the location of a particular ground water monitoring well to monitor the facility effectively is in conflict with the Rule's prescription for well location, and will require a variance from the Commission. The ability to rely on the information acquired through a hydrogeological characterization is muted by the singular focus on gradient and distance from a potential contamination source. By prescribing these two parameters for the location of monitoring wells to the exclusion of other relevant information available from the hydrogeological characterization establishes a false sense of environmental security that exposes the Permittee to environmental liability. The DIGCE proposed relief from the constraints imposed on the prescriptive location of monitoring wells relative to the potential contamination sources allows the Permittee (with the guidance of a qualified professional) the flexibility to locate a ground water monitoring well properly, based on surface and sub-surface conditions defined in a characterization of the hydrogeology. The result of allowing this flexibility provides effective monitoring of the ground water without the requirement to seek a variance from the Commission to allow proper monitor well placement.

4.29. In your opinion, if the Commission accepts the amendments proposed by DIGCE to 20.6.6.23 NMAC, will monitoring well systems still be required that will meet the purpose for monitoring well systems as set forth in 20.6.6.23(A)? State the reasons for your opinion.

Yes. The Permittee, with the support of their qualified professional, will still have the responsibility to characterize the ground water hydrogeology. This requirement to *understand the hydrogeology as it relates to the appropriate placement of ground water monitoring wells is imperative for the success of a detection monitoring program. Locating wells solely on the prescriptive requirements of gradient and proximity to a potential contamination source leaves the facility vulnerable to the potential hydrogeological variations and inconsistencies that may be present if the hydrogeological characteristics of the facility are not thoroughly understood. Positioning a monitoring well downgradient and within a prescribed distance from a potential contamination source does not ensure that the well is in the optimal location to evaluate properly the ground water quality beneath the facility. It is imperative to identify properly ground water monitoring well locations upgradient of the facility to benchmark the incoming water quality. It is equally important to define ground water monitoring locations downgradient of the facility in locations appropriately selected to detect exceedances, or a trend toward exceedances, at the earliest possible occurrence. This is the purpose of the proposed DIGCE revisions to this section of the current Rule.*

4.30. If the Commission accepts the amendments proposed by DIGCE to 20.6.6.23 NMAC, will there be any reduction in the effectiveness of ground water monitoring from those changes compared to the existing requirements?

No. In fact, the effectiveness of the ground water monitoring system will improve the quality of detection by optimizing the location of monitoring wells to detect an exceedance or trend toward an exceedance. By eliminating the prescriptive location standards for monitoring well locations and giving the permittee the opportunity to rely fully on their qualified professional's judgment in assessing the hydrogeological characteristics of a facility, the effectiveness of the ground water monitoring system will improve. This is the accepted practice for every regulatory ground water compliance program evaluated. Properly identifying the appropriate location of ground water monitoring wells will reduce the potential that a prescribed monitoring well installation might be required in an unacceptable location such as a road, drainage feature a lagoon embankment, etc. This flexibility will result in a ground water monitoring system that effectively reports the water quality present at the facility being monitored. Additionally, removal of the prescriptive monitoring well location requirements will reduce the number of variances that will come before the Commission requesting relief to optimize the ground water monitoring system at a facility. Having a Rule that routinely requires a variance is not productive. Implementing a Rule that significantly reduces the number of variance requests that must be heard by the Commission is justification enough to support these proposed changes, especially when the proposed amendments enhance ground water quality monitoring compliance and reduce environmental liability.

4.31. What are the reasons to amend the heading to 20.6.6.27(A) NMAC?

The proposed heading for §(A) is amended to make the contingency requirements for an exceedance of ground water standards applicable to all monitoring wells installed at a dairy facility. This proposed amendment simplifies the Rule by providing one section that addresses what actions are required when a ground water standard is exceeded. This simplification of the Rule removes the confusion represented by the various conditions *that may contribute to an exceedance of the standards, focusing attention on the required actions rather than the multitude of contributing conditions. DIGCE would also propose to strike the reference "...other than an impoundment ..." in the first sentence to make this section generically applicable to the all aspects of the entire dairy facility.*

4.32. What are the reasons to strike 20.6.6.27(B) NMAC?

The DIGCE proposal to strike §(B), related to the exceedance of ground water standards for impoundment monitoring wells is based on the fact that the proposed amendment of §(A) makes it applicable to all monitoring wells, thus eliminating the need for §(B) relating specifically to impoundment monitoring wells. This proposed amendment simplifies the Rule by providing one section (§(A)) that addresses what actions are required when a ground water standard is exceeded. This simplification of the Rule removes the confusion represented by the various conditions that may contribute to an exceedance of the standards, focusing attention on the required actions rather than the multitude of contributing conditions.

4.33. If the Commission adopts the proposed amendment to strike 20.6.6.27(B) NMAC, will contingency action still be required under 20.6.6.27(A) NMAC if monitoring well data shows an exceedance of ground water quality standards?

Yes. If the Commission adopts the proposed amendment to strike §(B), the contingency action requirements of §(A) will still apply if monitoring well sampling data show an exceedance of ground water quality standards in any monitoring well on the dairy facility. Having several similar contingency requirements differentiated only by the source of an exceedance is confusing. Focusing all of the attention to one section (§(A)) that addresses what contingency actions are required when a ground water standard is exceeded reduces the confusion. This simplification of the Rule removes the confusion represented by the various conditions that may contribute to an exceedance of the standards, focusing attention on the required actions rather than the multitude of contributing conditions.

4.34. How will the necessary action be determined?

Upon confirming an exceedance from any source within the dairy facility (as outlined in 20.6.6.27(A) NMAC), the Permittee is required to develop and submit a corrective action plan as outlined in 20.6.6.27 (A)(1). This section defines the timeline and necessary action that will be taken to address the exceedance, or to identify other data relevant to the investigation. DIGCE proposed no changes to this section, finding that it can be applied universally to the entire dairy facility as previously proposed.

4.35. Will additional investigation be required to determine what corrective action is necessary, compared to the operation of the existing dairy rule under 20.6.6.23 and .27(A) NMAC?

Yes. 20.6.6.27(A)(2) NMAC continues to provide the Permittee with the opportunity to initiate an investigation of potential contamination sources to determine which source *may be causing the exceedance. Once again, DIGCE proposed no changes to this section, finding that it can be applied universally to the entire dairy facility as previously proposed.*

4.36. What are the reasons for the proposed amendments to 20.6.6.27(C) NMAC (renumbered as subsection (B) under DIGCE's proposal)?

The DIGCE proposed amendments (replacing contamination source with dairy facility) are made in §(C) (renumbered as §(B) under DIGCE's proposal) to maintain consistency with the revisions made in 20.6.6.23(A) NMAC. In both cases, the revision refocuses attention on the development of a hydrogeological characterization of the entire location, and implementing an optimal ground water monitoring system that confirms facility compliance.

In addition, DIGCE proposes amendments that provide flexibility to the department to grant an extension of time for a Permittee to perform additional studies, provide replacement monitoring wells, perform surveys of the wells and provide monitoring well completion reports when good cause for the delay is provided.

4.37. What are the reasons for the proposed striking of 20.6.6.30(D) NMAC?

The DIGCE proposal to strike §(D) is based on the conclusion that the requirements of §(A) adequately address the actions associated with the discontinuance of ground water monitoring at a former impoundment. This section (§(D)) is repetitive and confusing with respect to its applicability. The deletion of this section will focus attention for the closure of former impoundment monitoring wells to §(A), where clear and concise requirements for all monitoring well closure activities are provided.

4.38. If the Commission strikes this section, will that adversely affect protection of ground water during and following closure of a dairy facility? If not, why not?

No. The requirements outlined in §(D) for post-closure monitoring are adequately addressed in §(B), providing the same level of compliance. Duplication of regulatory requirements, as observed in these two sections of the Rule, is confusing. The elimination of redundant regulatory requirements improves the potential for compliance.

4.39. What are the reasons for the proposed striking of 20.6.6.30(E) NMAC?

Once again, the DIGCE proposal to strike §(E) is based on the conclusion that the requirements of §(A) adequately address the requirements associated with the discontinuance of ground water monitoring at former land application fields. As with §(D), §(E) is also repetitive and confusing with respect to its applicability. The deletion of this section will focus attention for the closure of former land application monitoring wells to §(A), where clear and concise requirements for all monitoring well closure activities are provided.

4.40. If the Commission strikes this section, will that adversely affect protection of ground water during and following closure of a dairy facility? If not, why not?

No. The requirements outlined in §(E) for post-closure monitoring are adequately addressed in §(B), providing the same level of compliance. Duplication of regulatory requirements, as observed in these two sections of the Rule, is confusing. The elimination of redundant regulatory requirements improves the potential for compliance.

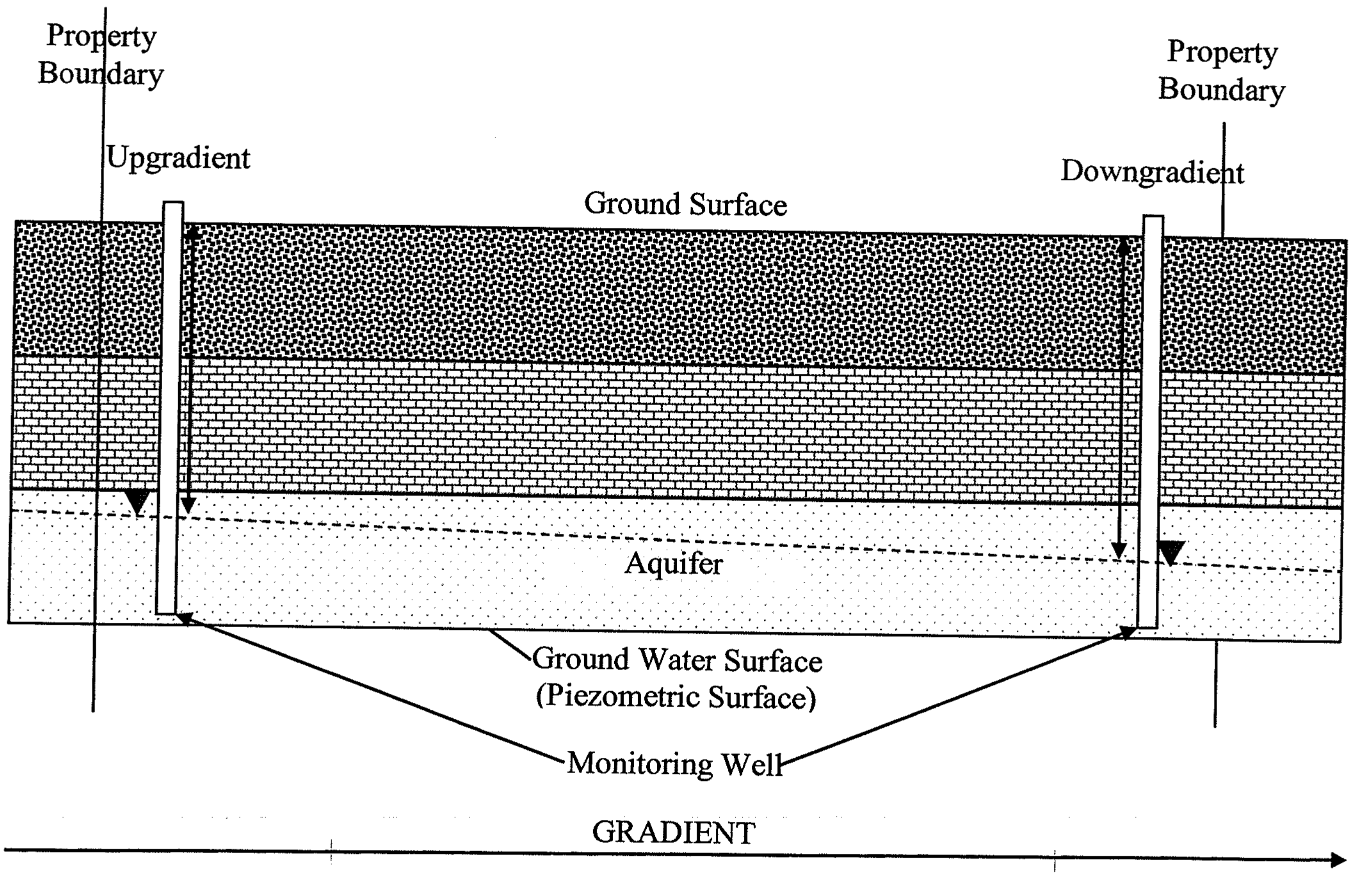
4.41. Is there any other information that the Commission should consider with respect to DIGCE's proposed amendments to the dairy rule provisions regarding ground water monitoring?

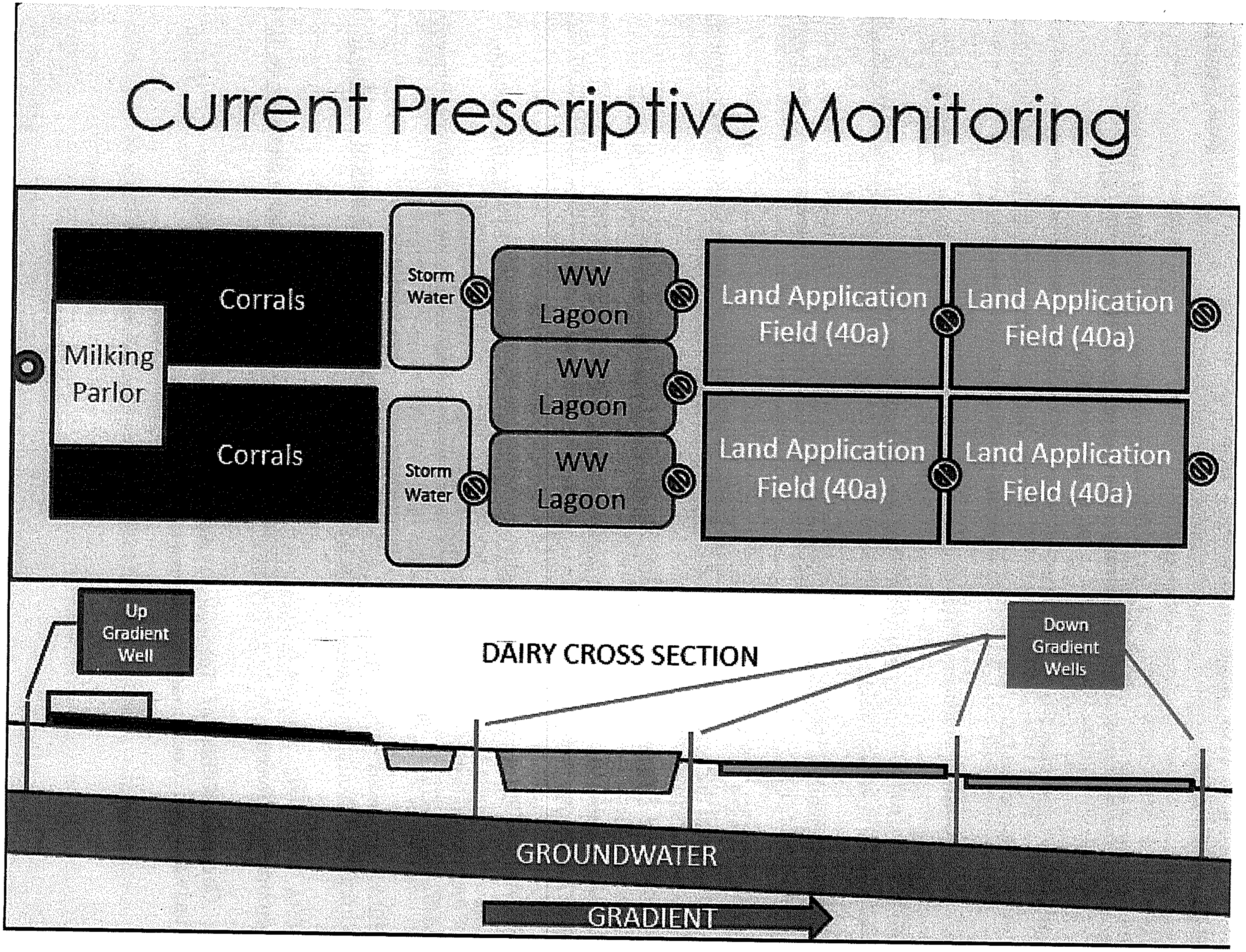
Yes.

- *The Commission should consider the DIGCE's proposed amendments to the current Dairy Rule as constructive criticism focused on the ground water monitoring requirements that are designed to provide improved compliance with the ground water standards, as this portion of the Rule was implemented to protect.*
- *DIGCE has proposed providing flexibility in the development of a ground water monitoring system designed to provide optimum performance in identifying exceedances or trends toward exceedances. This proposed flexibility is based on over thirty years of regulatory experience refining how to accomplish the task of characterizing the hydrogeological conditions at a location.*
- *I evaluated similar regulatory programs to assess their approach to ground water monitoring and found great similarity in their approaches which support many of the proposed enhancements presented.*
- *I have serious concerns with the prescriptive nature of the current Dairy Rule which leaves little opportunity for the Permittee to optimize the efficiency of their ground water monitoring system.*
- *My testimony focuses on developing a hydrogeologic characterization as the basis of all ground water monitoring system installations, providing for optimal monitoring well placement that provides the Permittee the level of confidence that their dairy is adequately protecting the ground water quality.*
- *DIGCE's proposed changes would simplify the Rule, striking sections that provided redundant requirements with no perceived additional benefit.*

Charles W. Fiedler, P.E.

GROUND WATER GRADIENT




Current Prescriptive Monitoring
Milking Parlor
Corrals
Corrals
Storm Water
Storm Water
WW Lagoon
WW Lagoon
WW Lagoon
Land Application Field (40a)
Land Application Field (40a)
Land Application Field (40a)
Land Application Field (40a)
Up Gradient Well
DAIRY CROSS SECTION
Down Gradient Wells
GROUNDWATER
GRADIENT

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STATE OF NEW MEXICO
BEFORE THE WATER QUALITY CONTROL COMMISSION

In the Matter of: **PROPOSED AMENDMENT** **TO 20.6.6 NMAC (Dairy Rule)**	)	**No. WQCC 13-08 (R)**

DIRECT TESTIMONY OF LONEY ASHCRAFT

My name is Loney Ashcraft. My residence address is #1 La Placita, Roswell, New Mexico. I hold a B.S. degree in Agricultural Economics/Agriculture Business from New Mexico State University from which I graduated in 1969.

I currently own and operate a business known as Ashcraft Consulting that is located at the same address as my residence. Through that business I provide dairy consulting services, which I have done for ten years. Before starting Ashcraft Consulting, I was employed for 36 years with the U.S. Department of Agriculture Soil Conservation Service, now known as the Natural Resource Conservation Service (NRCS), with 30 years as District Conservationist.

I hold the following certifications relating to my work as a dairy consultant: New Mexico Comprehensive Nutrient Management Plan ("CNMP") and Certified Crop Advisor (CCA). I also have completed the following courses of training provided by the NRCS: Water Quality (November 1, 1998); Agricultural Waste Systems II (April 27, 2001); Nutrient/Pest Management in Conservation Planning (April 24, 2002); Nutrient and Pest Management Online (December 3, 2001); and CNMP Planning (September 21, 2001).

In my positions as a dairy consultant and with the NRCS, I have worked with dairy operations for over 35 years in planning and designing wastewater storage systems and manure management. During this time I also have designed and constructed several types of irrigation systems, including center pivot, side roll and linear sprinkler systems, gravity or surface flow systems, and drip systems. Several of these systems are used for land application of dairy wastewater. I have prepared numerous farm and ranch resource conservation plans, ranch plans for ranches of sizes up to approximately 60,000 acres, and farm plans for various size farms up to approximately 3,500 acres. I am experienced with both range management and cropland management. I have prepared numerous applications for dairy discharge permits.

I am providing this testimony on behalf of the Dairy Industry Group for a Clean Environment, Inc. (DIGCE) to provide this testimony in support of certain of DIGCE's proposed amendments to the Water Quality Control Commission's dairy rules, 20.6.6 NMAC as set forth in DIGCE's "Second Petition" filed in matter No. WQCC 13-08 (R). The specific changes that are addressed by my testimony herein are set forth below as they appear in DIGCE's Second Petition, although they have been grouped by topic for ease of review.

I previously provided written direct testimony in matter No. WQCC 12-09(R) regarding DIGCE's proposed amendments to the Water Quality Control Commission's dairy rules regarding nutrient management plan requirements, backflow prevention requirements, and requirements for calibration of flow meters. That testimony remains as my direct testimony for those changes, and I have no changes to that testimony. I have reviewed, am in support of and recommend that the Commission adopt the amendments to the dairy rules as contained in the Second Petition to Amend 20.6.6 NMAC (Dairy Rule) as filed with the Commission.

DIGCE'S PROPOSED AMENDMENTS RELATING TO MANURE SOLIDS SEPARATORS

I offer the following direct testimony in support of DIGCE's proposed amendments to certain provisions relating to various types of mechanisms used to separate and/ or settle solids from dairy wastewater. The primary purpose of solids separation for most New Mexico dairies is to reduce solids in stored liquids to better facilitate land application of liquids using irrigation techniques. Excessive solids in wastewater that is land-applied through irrigation systems is undesirable due to potential plugging and wear of irrigation system components such as pumps, pipes, and particularly nozzles used for land application through sprinkler systems. For a few dairies, solids settling may facilitate treatment and handling of wastewater in digesters or other treatment units and may be employed to reduce accumulation of solids in storage and evaporative impoundments.

Many different methods are used to separate solids from wastewater, depending upon a number of factors. These methods include the use of a variety of filtration or screening devices and structures such as settling tanks, settling basins, or settling channels. Whatever method is used, the separated solids must be removed and handled. Solids removal can be accomplished by a variety of methods, including agitation and pumping or mechanical removal by equipment such as front-end loaders.

DIGCE's offers proposed amendments to several provisions of the dairy rules in order to recognize the variety of methods used for solids separation, to maintain flexibility in choosing an appropriate solids separation method, to avoid application of unnecessary and inappropriate design requirements for solids separation devices, particularly concrete structures, and to ensure that existing dairies that have and continue to function properly are not required to change existing solids separation practices or to unnecessarily employ solids separation if the existing dairy is functioning in a satisfactory manner without solids separation. Solids separation has little or no relationship to protection of ground water, and I believe that the existing rules impose unnecessarily prescriptive and detailed requirements that may be important for dairy management, but are not necessary for ground water protection.

The amendments, as proposed by DIGCE, which I will address in my testimony are quoted below, followed by questions and answers regarding those proposed amendments.

20.6.6.7 DEFINITIONS:

. . . .

(18) "Impoundment" means any structure designed and used for storage or disposal by evaporation of wastewater, stormwater, or a combination of both wastewater and stormwater~~, or used for solids settling~~. A multiple-cell impoundment system having at least one shared berm or barrier whose smallest cells have a cumulative constructed capacity of 10 percent or less of the constructed capacity of the largest cell shall be considered a single impoundment for the purposes of the dairy rule. A wastewater or stormwater transfer sump <u>or a solids settling separator</u> is not an impoundment.

Q. *DIGCE proposes to change the definition of "impoundment" in 20.6.6.7(B)(18) by deleting the words "or used for solids settling" in the second line and by adding the words "or a solids settling separator" in the last sentence of the definition. What are the reasons for these changes?*

A. Under the definition quoted above, without the DIGCE changes, ready literally it includes as an impoundment ". . .any structure . . . used for solids settling . . . ." A variety of different types of structures are used for solids settling, including concrete settling basins and channels. Concrete structures are not typically thought of as impoundments and should not be regulated as impoundments under the Dairy Rule for several reasons. For example, impoundments are subject to some specific design requirements, 20.6.6.17(C)(1)-(3) and (D)(1)-(2) and (4)-(9) NMAC. Several of these requirements, such as the liner requirements, are not practical, if applied to concrete structures used for solids settling. Without the rule change proposed by DIGCE, these design requirements for "impoundments" may technically apply to concrete solids settling structures. I do not believe this was intended by the Commission. Concrete solids settling structures also could be subject to separate ground water monitoring requirements for wastewater impoundments under 20.6.6.23(A)(1) NMAC of the existing rule. I do not believe that such monitoring requirements were intended or should be required for concrete solids settling structures, ect.

Q. Based on your experience, how would DIGCE's proposed changes to the definition of "impoundment" relate to protection of ground water quality?

A. I do not believe that DIGCE's proposed changes to the definition will reduce protection of ground water quality. Solids separation in general has little or nothing to do with ground water protection. As discussed above, for most New Mexico dairies its purpose is to protect irrigation equipment.

20.6.6.17 ENGINEERING AND SURVEYING REQUIREMENTS FOR ALL DAIRY FACILITIES:

. . . .

C. Engineering plans and specifications requirements.

. . . .

(5) **Manure solids separation plans and specifications - existing wastewater system.** An applicant or permittee proposing or required to construct a new manure solids separator as a component of an existing wastewater storage or disposal system shall submit a scaled design schematic and supporting documentation, including design calculations. The separator shall be designed to accommodate, at a minimum, the maximum daily discharge volume authorized by the discharge permit, and the volume of manure solids associated with the wastewater discharge. Components of the separator that collect, contain or store manure solids prior to removal or land application shall be designed with an impervious material(s) to minimize generation and infiltration of leachate.

~~(a)~~ A scaled design schematic and supporting documentation for a proposed separator shall be submitted to the department with the application for a new, renewed or modified discharge permit.

~~(b) A scaled design schematic and supporting documentation for a separator not proposed by the applicant or permittee but required to achieve compliance with the dairy rule shall be submitted to the department within 90 days of the effective date of the discharge permit.~~

Q. DIGCE proposes to delete subparagraph 20.6.6.17(C)(5)(b). What are the reasons for this changes?

A. This change is proposed in conjunction with the proposed amendment to 20.6.6.20(F), the next change addressed below, and the reasons for those proposed changes are discussed below. If the Commission adopts DIGCE's proposed changes to 20.6.6.20(F), which would eliminate a prescriptive requirement for "a manure solid separator" for existing dairies, then the

Department will not be requiring a manure solid separator for an existing dairy. Subparagraph (a) of this section would continue to require submission of a design schematic and supporting documentation for a new or modified manure solid separator proposed by the permit holder for an existing dairy.

Q. In your experience, how would this change relate to protection of ground water quality?

A. As previously discussed, solids separation is a management question and has little or no relationship to ground water protection. Consequently, I do not believe that this proposed change, of not requiring a solids separation, will reduce protection of ground water quality.

20.6.6.20 OPERATIONAL REQUIREMENTS FOR ALL DAIRY FACILITIES:

F. Manure solids separator installation – New Wastewater system. A permittee shall employ manure solids separation. ~~All wastewater discharges to an impoundment shall be made through a manure solid separator.~~

~~(1)~~ A permittee installing a new wastewater storage or disposal system shall, before discharging to the new system, construct a manure solids separator(s) in accordance with the construction plans and specifications submitted with the application for a new, renewed or modified discharge permit, or those submitted after issuance of a discharge permit to achieve compliance with the dairy rule. Before discharging to the new system, the permittee shall submit to the department confirmation of solids separator construction, including separator type(s) and location(s).

~~(2) If an existing dairy facility does not employ manure solids separation, the permittee shall construct a manure solids separator(s) within 150 days of the effective date of the discharge permit. The permittee shall submit confirmation of solids separator construction, including separator type(s) and location(s), to the department within 180 days of the effective date of the discharge permit.~~

Q. DIGCE proposes to delete a sentence in 20.6.6.20(F) which states: "All wastewater discharges to an impoundment shall be made through a manure solid separator." What are the reasons for this change?

A. To eliminate the requirement that a solids separator be used. There are a variety of methods used for solids separation both mechanical and passive each with varying degrees of efficiency. However, not all facilities require a separator to operate properly, and the arbitrary requirement to use them encroaches on the management's authority.

Q. DIGCE proposes to delete paragraph 20.6.6.20(F)(2). What are the reasons for this change?

A. This proposed change relates to the previously proposed amendment to 20.6.6.17(C)(5)(b) and would eliminate the Dairy Rule requirement for an existing facility that does not "employ manure solids separation" to construct a manure solid separator within a specified timeframe. As discussed above, there are many acceptable and technically sound methods to separate solids from wastewater. A few smaller dairies may collect wastewater in a tank and apply it directly to land application areas using a "honey wagon." In that case, there also is no need for solids separation.

Q. In your experience, how would these changes relate to protection of ground water quality?

A. As I have previously testified, I do not see a relationship between mandatory solid separation and ground water protection. Solid separation is typically, but not always, useful for dairy management as part of an overall wastewater management system, but some dairies either achieve solid mechanically/passive or directly apply wastewater without solid separation. I do not believe that ground water protection is sacrificed in either case.

TESTIMONY IN SUPPORT OF CHANGES RELATING TO FLOW METERING

The next few amendments proposed by DIGCE relate to the requirements for flow metering. These changes do not fundamentally change the flow metering requirements in the existing Dairy Rule, but are designed to eliminate confusion in the existing Dairy Rule, provide for more flexibility for the Department to approve some alternative flow metering approaches without the need for variances, and to eliminate unnecessary requirements.

20.6.6.17 ENGINEERING AND SURVEYING REQUIREMENTS FOR ALL DAIRY FACILITIES:

. . . .

C. **Engineering plans and specifications requirements.**

. . . .

(7) **Flow metering plans [~~and specifications~~].** An applicant or permittee proposing or required to install a flow meter(s) shall submit documentation to support the selection of the proposed device as appropriate for the expected flow rate along with a description of the location and information on the installation or construction of each device.

(a) Such information proposed by the applicant or permittee shall be submitted to the department with the application for a new, renewed or modified discharge permit.

(b) Such information not proposed by the applicant or permittee but required to achieve compliance with the dairy rule shall be submitted to the department within 90 days of the effective date of the discharge permit.

Q. DIGCE proposes to delete the words "and specifications" from the heading to 20.6.6.17(C)(7). What are the reasons for this change?

A. This change is proposed to reflect that the text of the paragraph to which the heading applies does not mention or require submission of flow metering specifications. This is a non-substantive change to avoid confusion that might arise if the heading uses the term "specification" but the text does not.

20.6.6.20 OPERATIONAL REQUIREMENTS FOR ALL DAIRY FACILITIES:

. . . .

J. **Flow meter installation.** A permittee shall employ a flow metering system that uses flow measurement devices (flow meters) to measure the volume of wastewater discharged at the dairy facility. Flow meters shall be installed in accordance with the plans submitted with the application for a new, renewed or modified discharge ermit, or those submitted after issuance of a discharge permit to achieve compliance with the dairy rule, pursuant to his section, Subsection C of 20.6.6.17 NMAC, and Subsections G and H of 20.6.6.21 NMAC. Flow meters shall be ~~physically and permanently~~ labeled with the discharge permit number, meter identification nomenclature as pecified in a discharge permit, and the month and year of meter installation.

Q. DIGCE proposes to delete the words "physically and permanently" from the third sentence of 20.6.6.20(J). What are the reasons for this change?

A. The proposed change does not eliminate the labeling requirement, but allows for the use of more practical labeling methods. It is not entirely clear what is meant by "physical and permanent" labeling, but it could mean that the rule requires something like an engraved metal plate. In my opinion, there is little purpose or need for the labeling required by the existing rule. However, DIGCE is not proposing to eliminate the labeling requirement, just to allow simpler labeling methods. For example, a permanent marker could be easily used to label a flow meter with the required information with the same result but without the unnecessary trouble and expense of designing, purchasing and installing an engraved metal plate.

Q. In your experience, how would this change relate to protection of ground water quality?

A. I do not see any relationship in the method of labeling and ground water protection.

K. Flow metering methods. Flow metering shall be accomplished by the following methods.

(1) For pumped flow discharge or transfer situations, an applicant or permittee shall install a closed-pipe velocity sensing totalizing flow meter(s) on the pressurized discharge or transfer line(s).

(2) For gravity flow discharge or transfer situations, an applicant or permittee shall install a closed pipe totaling flow meter or an open-channel primary flow measuring device(s) (flume or weir), equipped with head sensing and totalizing mechanisms, on the discharge or transfer line(s).

(3) An applicant may propose and the department may accept a proposal to meter flows by metering the water supply. The proposal shall provide specific detail regarding the flow meter to be used and the relationship between the volume of water supplied and wastewater volume.

Q. DIGCE proposes to add the words "a closed pipe totaling flow meter" to paragraph 20.6.6.20(K)(2). What are the reasons for this change?

A. The existing rule appears to prohibit the use of a closed pipe with a totalizing flow meter if wastewater flows by gravity and pumping is not used. Given the right circumstances and proper design a totalizing flow meter could be used in gravity flow applications. By the way, the word "totaling" in the proposed rule language should be changed to "totalizing." Consequently, DIGCE proposes to expressly allow for the use of closed pipe conveyances with totalizing flow meters in gravity-flow situations, not just pumped water applications.

Q. DIGCE proposes to add a new paragraph 20.6.6.20(K)(3) that would allow the Department to accept a proposal to meter wastewater flows by metering the water supply. What are the reasons for this change?

A. Many existing discharge permits allow the measurement or estimation of wastewater flow rates and volumes based on metering the water supply at a point that represents all water used for washing or any other use that generates wastewater. This is a reasonably accurate method as there is a direct relationship between the volume of water supplied for washing and the volume of wastewater generated.

Use of flow meters to measure a water supply also is a superior method because it is easier to maintain a flow meter on a "clean" water supply than wastewater. Wastewater contains solids and other materials that can interfere with a flow meter that requires more maintenance or limit the life of the flow meter. Consequently, metering of water supply is usually more reliable and consistent than metering wastewater.

DIGCE's proposed change would not automatically allow for metering a water supply rather than directly metering wastewater, but would require a specific proposal from the permit applicant showing that the water supply would be metered at a location representative of the volume of water that becomes wastewater and any other factors that should be considered in using measurements of water supply to estimate wastewater volumes. If the Department does not find the proposal to be acceptable, it does not have to approve the proposed metering method. In my opinion, this is a reasonable issue to allow the Department to vary from the prescriptive rule requirements without the need for a variance.

Q. In your experience, how are these changes related to protection of ground water quality?

In my experience there are numerous instances that metering the supply could and should be considered as an option. Consequently, I do not believe that there would be any sacrifice of ground water quality if the Commission authorizes the Department to accept a plan for an alternative metering method.

CHANGES RELATING TO LAND APPLICATION OF WASTEWATER

20.6.6.21 ADDITIONAL OPERATIONAL REQUIREMENTS FOR DAIRY FACILITIES WITH A LAND APPLICATION AREA:

. . . .

C. Land application area - fresh irrigation water required. Wastewater shall only be applied to fields within the land application area receiving fresh irrigation water. Fresh irrigation water shall be used as the primary source to meet the water consumptive needs of the crop to support crop production and nutrient removal. Wastewater and stormwater are intended as sources of crop nutrients and shall not be used as a primary source to meet the water consumptive needs of the crop. An applicant may propose and the department may accept a proposal to apply wastewater to crops or grazing land without using fresh water for irrigation if the proposal demonstrates to the department's satisfaction that crops or plants to be grazed can be successfully maintained without fresh irrigation water.

Q. DIGCE proposes to add a sentence to 20.6.6.21(C) NMAC that would allow the Department to accept a proposal to apply wastewater to crops or grazing land without using fresh water for irrigation. What are the reasons for this change?

A. This provision of the Dairy rule allows land application of wastewater only to a field that receives fresh irrigation water. In some parts of New Mexico, this may be appropriate as crops cannot be grown successfully without irrigation. However, there are parts of the state, such the eastern High Plains, including Curry and Roosevelt counties, where crops are successfully grown without irrigation using fresh water. In these areas, it is practicable to apply dairy wastewater to fertilize fallow ground prior to planting. The wastewater can be applied to provide nutrients at agronomic rates to the benefit of the crops planned to be grown without any harm to the crops. typically, this practice would not be utilized by a large dairy, but there are small dairies that can practicably apply stored wastewater to dry land crops in this manner.

DIGCE's proposed rule change would allow a dairy who can successfully operate in this manner to propose land application of wastewater for dry land crops and would allow the Department to accept that proposal if the applicant shows that crops can be successfully maintained without irrigation.

Q. In your experience, is it reasonable to expect that crops can be maintained if wastewater is applied without fresh irrigation water? If so, are there any particular circumstances that should be considered?

A. Yes, as discussed above, crops can be grown in parts of the state, though not the entire state, without fresh irrigation water. Factors that should be considered are annual and seasonal rainfall and local experience with successful dry land crops.

Q. In your experience, how would this practice relate to protection of ground water quality?

A. If dry land crops can be grown successfully, and wastewater is applied, along with other fertilizers as needed, at agronomic rates in accordance with a nutrient management plan, the application of wastewater for dry land can be accomplished without impacting ground water.

G. Flow metering - wastewater to land application area. A permittee shall install flow meters to measure the volume of wastewater discharged from the wastewater or combination wastewater/stormwater impoundments to the land application area. The flow meter(s) shall be installed on the discharge line(s) from the wastewater impoundment(s) <u>or tank</u> to the distribution system for the land application area. Meter installation and confirmation of meter installation shall be performed pursuant to Subsections J, K and M of 20.6.6.20 NMAC.

Q. DIGCE proposes to add the words "or tank" to 20.6.6.21(G). What are the reasons for this change?

A. Some dairies may utilize a tank for temporary storage of wastewater prior to land application. DIGCE's propose change simply clarifies that if a tank is used, the flow meter can be installed between the tank and the distribution system, rather than between an impoundment and the tank. It also accounts for a few situations, typically at small dairies, where wastewater is collected in a tank rather than an impoundment. In my opinion, this change would not affect the quality of the data collected from the flow meter to show the volume of wastewater that is land-applied and would have no effect on ground water quality.

J. **Crop removal - mechanical or grazing.** A permittee shall remove crops from fields within the land application area by mechanical harvest ~~unless an alternative proposal for the use of~~or grazing ~~is submitted with the application for a new, renewed, or modified discharge permit. If grazing is the method proposed for crop removal, the nutrient management plan (NMP) prepared pursuant to Subsection [K]~~ I ~~of this section shall include a proposal for the use of grazing for crop removal by means of an actively managed rotational grazing system which promotes uniform grazing and waste distribution throughout the field(s) (and pastures within the field). Proposals shall quantify the degree of nitrogen removal expected to be achieved by grazing, and shall provide scientific documentation supporting the estimated nitrogen removal and justification for the selection of input parameters used in calculations or computer modeling. The NMP proposing grazing for crop removal shall be implemented in its entirety. Annual updates to the NMP shall include updates to the grazing plan as well as a report of actual weight gains, actual nitrogen uptake of the crop, and estimated crop and nutrient removal from the previous season.~~ An NMP which proposes grazing for crop removal shall also include, at a minimum, estimated values for the following elements.

(1) The length of the grazing season.
(2) The size and number of animals to be grazed.
(3) The estimated weight gain of animals to be grazed, or estimated intake for maintenance or milk production.
(4) The calculations to determine stocking rates, total acreage needed and residency period.
(5) The plant species used to establish pastures and the pasture renovation practices to be employed.
(6) The yield of plant species grown in each pasture and the forage supplied on a monthly basis.
(7) The grazing management system employed and a map indicating key features of the system including water tanks, fencing, and pasture layout with numbering system and acreage of each pasture.

Q. DIGCE proposes to delete language from 20.6.6.21(J) NMAC specifying requirements for a proposal for crop removal by grazing. What are the reasons for these changes?

A. The current rule language requires a special showing and scientific documentation in order to account for nitrogen removal by crops are harvested by grazing. However, harvesting crops by grazing is a normal standard practice that will be adequately addressed in the NMP. The existing documentation requirements are excessive and not necessary. Nitrogen utilization is more a related to crop selection than the method of harvest. The NRCS 590 job sheet already estimates the nutrient requirements based on type of crop planted and whether they are harvested for grain, hay, silage or by grazing. I have attached as exhibit "Ashcraft - 1" copies of two examples of NRCS standard job sheets for crops harvested by grazing, in this particular case bermuda grass pasture. Harvesting the crops by grazing or otherwise simply removes some of the plant mass that contains a portion of the nitrogen removed from the soil by the growing crops. When crops are removed by grazing, the grazing animals leave a limited amount of manure in the grazed areas, but the amount of manure left be grazing animals is minimal not generally significant in determining appropriate nitrogen application rates. The required annual soil test will be used to more accurately address any potential ground water problems.

Q. Without the language that DIGCE proposes to strike, would the contents of a nutrient management plan be sufficient to estimate nitrogen removal by grazing?

A. DIGCE's proposal would retain rule language requiring various metrics pertaining to the grazing and crops that can be used to estimate nitrogen removal by grazing. The more direct means of measuring nitrogen in the soils and avoiding over application of nitrogen is the soil sampling required by the rule. Soil sampling will determine nutrient requirements for the cropping system.

Q. In your experience, how would this proposed change relate to protection of ground water quality?

A. The concern as it relates to ground water protection is the accumulation of excess nitrogen in soils due to over application of wastewater and fertilizer over time, such that the excess nitrogen can potentially leach from the soils into ground water. I do not believe that adoption of DIGCE's proposed change to this section will have any effect on protection of ground water quality. As discussed above, in my opinion the "mass balance" approach relating the nitrogen application and removal is a secondary method of measurement as it relates to nutrient management, with soil sampling being the primary measure and protection.

~~K. Crop removal - changes to method(s).~~ ~~If a permittee proposes to change the method(s) (i.e., mechanical versus grazing) of crop removal on any field within the land application area authorized by the discharge permit, the permittee shall apply to modify the discharge permit. The permittee shall submit an application which includes the proposed change(s) pursuant to Subsection I and J of this section. The permittee shall not implement the changes unless the department issues a modified permit approving the changes.~~

Q. DIGCE proposes to delete subsection 20.6.6.21(K) regarding a requirement to modify a permit for changes to crop removal methods. What are the reasons for these changes?

A. My concern with this subsection is that it would require a permit "modification" in order to change the method of harvesting crops. This is not practicable due to the time and expense required for a permit modification and the need to change crops harvesting methods that may arise due to weather conditions, including precipitation and hail, market conditions, and other factors. Foreseeable changes in crop removal methods can be identified in a nutrient management plan and actual crop removal practices can be accounted for in implementation of the nutrient management plan without the need for a permit modification.

Q. In your experience, how would this proposed change relate to protection of ground water quality?

A. In my opinion, this change will have no bearing on protection of ground water quality. As I have previously testified, crop removal methods and harvesting is considered primarily with respect to mass balance calculations to show nitrogen removal. However, in my experience and opinion, this is a secondary check for nutrient management. The primary measurement used by nutrient management planners to determine appropriate nutrient application rates is crop selection and soil sampling.

TESTIMONY ON CHANGES RELATING TO SAMPLING REQUIREMENTS

20.6.6.24 MONITORING REQUIREMENTS FOR ALL DAIRY FACILITIES:

. . . .

D. Stormwater sampling and reporting. A permittee shall collect stormwater samples on a quarterly basis from each stormwater impoundment unless the stormwater will be transferred ~~. The samples shall be collected as soon as possible after a storm event and before transferring the stormwater~~ to a wastewater impoundment(s) ~~or~~before being sent to the land application area. The samples shall be analyzed for nitrate as nitrogen, total Kjeldahl nitrogen, chloride, total sulfur and total dissolved solids pursuant to this section. The permittee shall include analytical results, or a statement that stormwater runoff did not occur, in the quarterly monitoring reports submitted to the department.

Q. DIGCE proposes to change the sampling requirements for stormwater impoundments if the stormwater will be transferred to a wastewater impoundment before being sent to a land application area. What are the reasons for these changes?

A. The primary reason to sample stormwater is to determine the nutrient content of the stormwater that will be applied to the land. DIGCE's change would reduce separate stormwater sampling and analysis if stormwater is mixed with wastewater before land application. When stormwater is mixed with wastewater prior to land application, the nutrient content of the stormwater is accounted for through sampling of the mixture of wastewater and stormwater. Also, stormwater that is mixed with wastewater prior to application is not measured, therefore the sampling and analysis would be of little value.

Q. In your experience, how would the change to this sampling requirement relate to protection of ground water quality?

A. In my opinion, DIGCE's change, if adopted by the Commission, would have no bearing on protection of ground water quality.

20.6.6.25 ADDITIONAL MONITORING REQUIREMENTS FOR DAIRY FACILITIES WITH A LAND APPLICATION AREA:

. . . .

C. Wastewater to be land applied - sampling and reporting. A permittee shall collect and analyze wastewater samples on ~~a quarterly~~an annual basis for nitrate as nitrogen, total Kjeldahl nitrogen, chloride, total sulfur and total dissolved solids pursuant to Subsection B of 20.6.6.24 NMAC. Representative samples shall be collected from the wastewater impoundments unless an alternative method is approved for good cause, including safety. The representative samples shall consist of eight samples taken from eight different locations evenly distributed throughout the impoundment or using an alternative method approved by the department for good cause. A permittee shall submit the analytical results to the department in the quarterly monitoring reports.

Q. DIGCE proposes to change the frequency for sampling wastewater. What are the reasons for this change?

A. Sampling of wastewater, particularly from an impoundment, is costly and somewhat hazardous. Especially since the sampling method specified in the rule requires collection of samples from eight locations within an impoundment to be composited. The results of these samples are used for estimating the nitrogen loading in preparation of the NMP. These results are variable and of limited value compared to the annual soil sampling. Due to the potential hazards and expense sampling, the sampling events should be limited to annually or biannually with minimal impact.

Q. In your experience, would how would this reduction in sampling frequency relate to protection of ground water quality?

A. In my view, reduction of the sampling frequency will not impact protection of ground water quality. Annual or biannual sampling, in conjunction with past data used as a check, can provide a reasonable estimate of the nutrient content of wastewater suitable for planning purposes.

Q. DIGCE also proposes a change that would allow the Department to approve an alternative method for sampling. What are the reasons for this change?

A. Alternate methods could be more reliable than taking samples directly from an impoundment. In some instances it may be practicable to take samples from pipes or sumps being used to remove wastewater from the impoundment. That sampling method can provide a more direct measure of nutrients in wastewater going to land application. The Department would have to accept and approve an alternative method before it could be used.

E. Irrigation water - sampling, volume applied, and reporting. A permittee shall monitor irrigation wells used to supply fresh water to the fields within the land application area to account for additional potential nitrogen supplied to the land application area in the following manner.

(1) Each irrigation well shall be identified in association with the field(s) to which it supplies fresh water.

(2) ~~An annual~~ A sample of irrigation water supplied from each well or a group of wells if more than one well supplies a field shall be collected and analyzed for nitrate as nitrogen and total Kjeldahl nitrogen at least once every five years, pursuant to Subsection B of 20.6.6.24 NMAC.

(3) The annual volume of irrigation water applied to each field within the land application area shall be estimated ~~for each well~~.

(4) The permittee shall submit the analytical results and the estimated annual volume of irrigation water applied ~~from each well~~ to each field within the land application area to the department in the monitoring reports due by May 1.

Q. DIGCE proposes to change the requirement to sample irrigation water from annually to once every five years. What are the reasons for this proposed change?

A. Generally nitrate/nitrogen levels in irrigation wells are fairly stable with small variances and annual sampling would not be necessary.

Q. DIGCE also proposes to change these requirements so that volumes and analytical results do not have to be provided for each well. What are the reasons for this proposed change?

A. Most irrigation systems utilize more than one irrigation well. Sampling at the common outlet (field or pivot etc.) would adequately account for the values in the irrigation water.

Q. What is the sampling information used for?

A. The nitrogen values are used in estimating nitrogen loading in the Nutrient Management Plan.

Q. In your experience, will these proposed changes affect the quality of the information used for the nutrient management plan?

A. The proposed changes would have minimal or no effect on the quality of the nutrient management plan.

G. Land application data sheets. A permittee shall complete land application data sheets for each field within the land application area to document the crop grown and amount of total nitrogen applied from wastewater, stormwater, manure solids, composted material, irrigation water and other additional fertilizer(s), and the residual soil nitrogen and nitrogen credits from leguminous crops. The permittee shall submit a land application data sheet or a statement that land application did not occur to the department in the quarterly monitoring reports. The land application data sheet shall include the following elements ~~from the previous six quarters~~.

Q. DIGCE proposes to delete a requirement for a permittee to provide land application data sheet information from the previous six quarters. What are the reasons for this change?

A. The six quarter requirement does not appear to serve any practical function, especially since the soil sampling and NMP is completed and documented annually.

K. Soil sampling - initial event in a discharge permit term. A permittee shall collect composite soil samples from each field within the land application area for the first soil sampling event during the first year following the effective date of the discharge permit. Composite soil samples shall be collected ~~in the five-month period between September 1 and January 31~~ for all fields regardless of whether the field is cropped, remains fallow, or has received wastewater or stormwater. One surface composite soil sample (first-foot) and two sub-surface composite soil samples (second-foot and third-foot) shall be collected from each field. Composite soil samples shall be collected and analyzed according to the following procedure.

L. Soil sampling - routine. Beginning in the year following the initial soil sampling required by this section, the permittee shall collect annual soil samples from each field within the land application area that has received or is actively receiving wastewater or stormwater. ~~Composite soil samples shall be collected in the five-month period between September 1 and January 31.~~ For those fields that have never before received wastewater, the permittee shall collect soil samples immediately before initial wastewater application and annually thereafter. Once a field has received wastewater it shall be sampled annually regardless of whether the field is cropped, remains fallow, or has recently received wastewater or stormwater. One surface composite soil sample (first-foot) and two sub-surface composite soil samples (second-foot and third-foot) shall be collected from each field. Composite soil samples shall be collected and analyzed according to the following procedure.

Q. DIGCE proposes to delete a specified timeframe for collection of soil samples from subsections 20.6.6.25(K) and (L). What are the reasons for these changes?

A. Soil sampling is used for both crop production and ground water protection. Since the majority of the land application areas are "double cropped," *i.e.,* two crops are produced each year, there is no reason to limit the sampling dates to particular seasons.

Q. What is the soil sampling information used for?

A. As noted above, crop production and to prevent excessive nitrogen build-up in the soil.

Q. In your experience, will eliminating the specified time frame for collection of soil samples reduce the quality of information when used in a nutrient management plan?

A. This change would not have any effect on the quality of the Nutrient Management Plan

20.6.6.26 ADDITIONAL MONITORING REQUIREMENTS FOR DAIRY FACILITIES DISCHARGING TO AN EVAPORATIVE WASTEWATER DISPOSAL SYSTEM: Wastewater to be evaporated - sampling and reporting. A permittee shall collect a composite wastewater sample on a semi-annual (once every six months) basis from each wastewater or combination wastewater/stormwater impoundment used for disposal by evaporation. ~~The composite sample from each impoundment shall consist of a minimum of six sub-samples collected around the entire perimeter of each impoundment and thoroughly mixed.~~ Samples shall be analyzed for nitrate as nitrogen, total Kjeldahl nitrogen, chloride, total sulfur and total dissolved solids pursuant to Subsection B of 20.6.6.24 NMAC. A permittee shall submit the analytical results to the department in the monitoring reports due by May 1 and November 1

Q. DIGCE proposes to change the sampling method to collect samples from an evaporative wastewater disposal system. What are the reasons for this change?

A. If the wastewater is being evaporated and not land applied I do not see any value to sampling data, so complex sampling with six-subsamples is not necessary.

Q. In your experience, how would this change relate to protection of ground water quality?

A. It would not have any effect.

.20.6.6.30 CLOSURE REQUIREMENTS FOR ALL DAIRY FACILITIES:

A. Permanent closure of dairy facility or impoundments. The following closure actions shall be performed at dairy facilities.

(1) For permanent closure of a dairy facility.

(a) The department shall be notified no later than 30 days after wastewater discharge has permanently ceased at the dairy facility.

(b) Installation of ~~all~~ <u>any additional</u> monitoring wells shall be completed pursuant to 20.6.6.23 NMAC.

(c) All wastewater and combination wastewater/stormwater impoundments shall be emptied within six months of permanently ceasing wastewater discharge at the dairy facility; combination wastewater/stormwater impoundments may continue to receive stormwater after removal of the impounded wastewater/stormwater. All stormwater and combination wastewater /stormwater impoundments shall be emptied of stormwater within one year of ~~removing all livestock from the dairy facility~~<u>cessation of wastewater discharge</u>. Wastewater and stormwater removed from impoundments shall be applied to the designated land application area, as authorized by a discharge permit. In the event that land application is not authorized by a discharge permit, a disposal plan shall be submitted for department approval and the plan implemented upon department approval.

(d) Manure solids and compost shall be removed from surface areas at the dairy facility and applied to the designated land application area, as authorized by a discharge permit, or transferred off-site for proper disposal ~~within one year of removing all livestock from the facility~~.

(e) Complete removal of manure solids from the wastewater impoundment(s) shall be achieved within two years of permanently ceasing wastewater discharge. Complete removal of manure solids from the stormwater and combination wastewater/stormwater impoundment(s) shall be achieved within two years of ~~removing all livestock from the dairy facility~~cessation of wastewater discharge. Manure solids shall be applied to the designated land application area, as authorized by a discharge permit. In the event that land application is not authorized by a discharge permit, a disposal plan shall be submitted for department approval and the plan implemented upon department approval.

(f) Impoundment liners shall be perforated or removed and the impoundments shall be re-graded with clean fill to blend with surface topography to prevent ponding within two years of permanently ceasing wastewater discharge ~~and removing all livestock from the facility~~.

Q. DIGCE proposes changes to the closure section so that requirements to empty impoundments, to remove manure solids, and closure with respect to impoundment liners are changed so they relate to the cessation of wastewater discharges and do not relate to removal of livestock. What are the reasons for these changes?

A. Wastewater discharges at a dairy cease when cows are no longer being milked. A dairy can stop milking cows for many reasons, such as economic conditions, retirement, building a new dairy, or a decision to sell a dairy. However, when a decision is made to stop milking cows, that does not mean that the dairy will be permanently closed. In some instances, dairy lots may be used for other purposes, such as feeding heifers or other animals that are not milked. In some cases, a dairy owner will intend to hold the dairy for sale, and a sale can take some years to accomplish. In that case, the dairy owner will not want to lose the value of the assets, including features such as lined ponds. DIGCE's proposed changes are intended to reflect the different scenarios for dairy closure and to provide more flexibility.

The change to paragraph (1) subparagraph (b) to replace "all" with "any additional" is for clarity and is intended to reflect that, in most cases, the monitoring wells required by 20.6.6.23 NMAC will already be installed, and it will not be necessary to reinstall "all" of the monitoring wells.

The changes to paragraph (1) subparagraphs (c) and (e) are proposed because the activity regulated by the discharge permit program is the discharge of wastewater, not the regulation of livestock feeding. Consequently, removal of water and accumulated manure/solids from stormwater impoundments should be tied to cessation of wastewater discharges, not removal of all livestock. This change may actually have the effect of requiring removal of water and solids accumulated during dairy operations sooner, rather than later, in the case when dairy lots are used for feeding of other livestock. However, the Commission should be aware that stormwater ponds may remain in place after water accumulated during dairy operations is removed, and additional stormwater may collect in the impoundments after that.

The change to paragraph (1) subparagraph (d) recognizes that a dairy may be held for sale for a long period of time during which neither wastewater discharges nor the placement of livestock exist. Consequently, this change removes any specified time frame for removal of manure from surface areas. The removal of manure from all surface areas typically would be undertaken when an owner decides that the land where a dairy is located will no longer be used as a dairy and will be redeveloped for other purposes. The timeframe for that activity cannot be determined or specified by rule, as it is an economic decision of the owner.

The changes to paragraph (1), subparagraph (f) also reflect that closure activities should be tied to the regulated activity of wastewater discharges and not the feeding of other livestock. This is discussed above with regard to the changes to subparagraphs (c) and (e). There is a difference between those subparagraphs and subparagraph (f), however, in the subparagraph (f) requires liner perforation or removal only after a decision to "permanently" cease wastewater discharges. I understand that this is intended to mean that the dairy owner has decided that the facility will not be used as a dairy in the future or sold as a dairy and that the lined impoundments no longer are an asset to be preserved. As discussed above, this is an economic decision to be made by the owner.

Q. In your experience, how would these changes relate to protection of ground water quality?

A. I do not see any reason why these changes would have any bearing on protection of ground water quality. The changes are intended to clarify the requirements and timeline for a typical dairy closure and are tied largely to the distinction between the regulated activity of dairy discharges requiring a discharge permit and the feeding of other animals which is not regulated under the dairy rules.

This concludes my written direct testimony.

Electronically Approved 10/17/14
Loney Ashcraft

590 Nutrient Mgt. Jobsheet for Organic and Manure Land Application

Client Name:		Acres:	96	Date:	10/10/2014	Field ID:	1
Application information (*enter the units that will be or has been applied to the field*):	Crop Rotation: Pasture - Bermuda			Needed for field (acin):			384
	Liquid Applied:	4	AcIn/ac	(gal):			10,425,600
	Solids Applied:	10	ton/ac	Needed for field: Tons			960
	Liquid Loads Applied:		1000gal/ac	Loads needed for field:			

Nutrient Content of Organic Material

Solid-Lab Report	% Moisture	TKN (%) (dry)	NH_4-N (ppm) (dry)	P_2O_5 (%) (dry)	K_2O (%) (dry)
Fill in Lab data:					

Solid Book Values (select even if test values are used)	% Moisture		TKN (lbs/wet ton)		NH_4-N (lbs/ton)		P_2O_5 (lbs/wet ton)		K_2O (lbs/wet ton)	
	Book	Test	Book	Test	Book	Test	Book	Test	Book	Test
Dairy Cattle (30% wet wt) NM (Aver	30	0	25	0	0.4	0.0	17	0	35	0

Liquid-Lab Report	NH_3-N (mg/L)	TKN (mg/L)	NO_3-N (mg/L)	Tot-PO_4 (mg/L)	K (mg/L)
Fill in Lab data:		300			

Liquid	% Moisture		TKN (lbs/acin)		NH_4-N (lbs/acin)		P_2O_5 (lbs/acin)		K_2O (lbs/acin)	
	Book	Test	Book	Test	Book	Test	Book	Test	Book	Test
NM Dairy Ponds (>99.5% liq.) Ave.	99.5		0	68	0	41	22	0	93	0
			TKN (lbs/1000gal)		NH_4-N (lbs/1000gal)		P_2O_5 (lbs/1000gal)		K_2O (lbs/1000gal)	
			Book	Test	Book	Test	Book	Test	Book	Test
			0.0			0.0		0.0		0.0

N Volatilization

Solid (type of application)	Type of Climate	Percent Remaining	NH_4-N Remaining
Broadcast-incorporated in 4 days	Warm Dry	60 %	0 (lbs/ton) NH4-N
Liquid (type of application)	**Type of Climate**	**Percent Remaining**	24.8 (lbs/acin) NH4-N
Surface Irr w/o incorp & w/o crop canopy	Warm Dry	60 %	0.0 (lbs/1000gal) NH4-N

Mineralization of N, P, & K

Manure Source	Percent Nutrient Available the 1st Year			
	Organic N	P	K	
Beef & Dairy Solid w/o bedding	35 %	75 %	80 %	Solid Source
Lagoon or diluted Pond	40 %	75 %	80 %	Liquid Source

Solid	Organic N (lbs/ton)	P_2O_5 (lbs/ton)	K_2O (lbs/ton)
	9	13	28
Liquid	**Organic N (lbs/acin)**	**P_2O_5 (lbs/acin)**	**K_2O (lbs/acin)**
	11	16	75
	Organic N (lbs/100gal)	**P_2O_5 (lbs/1000gal)**	**K_2O (lbs/1000gal)**
	0.00	0.0	0.0

Denitrification of N

Organic Matter Content (%)	Soil Drainage Class (See Survey Information)	Percent Remaining (%)
2-5	Well Drained	80

Summary of Nutrients

Net by Form as applied	lbs/1000gal	lbs/ac in	lbs/ton
N	0.0	28	7
P_2O_5	0.0	16	13
K_2O	0.0	75	28

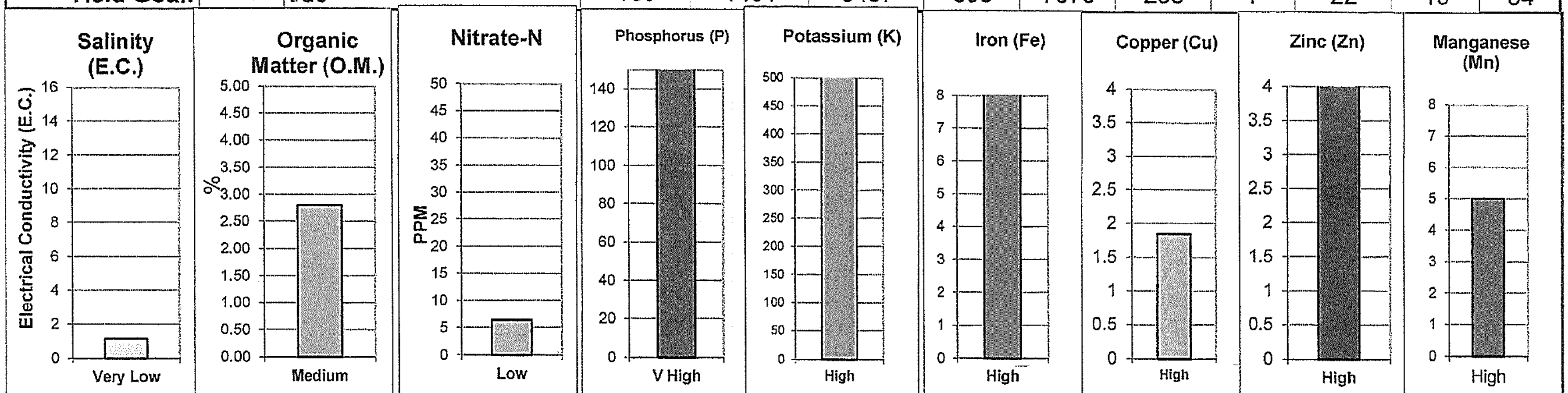
Total Nutrients Applied (net to the field)	All Forms N (lbs/ac)	P_2O_5 (lbs/ac)	K_2O (lbs/ac)
	183.8	195.6	581.1

N.M.S.U.-Soil Test Interpretation Report vs 5.1 - (590 Nutrient Management Jobsheet) June 2014

XC to County Agent:	CHAVES	Save To Farm Sum	Field ID: 1	Crop Rotation:	Pasture - Bermuda
Client Name:			Record #: 1	Square feet: or Acres:	96.000 Irr. Water (acin/ac): 33
Address:			Planner Name:	Form Notes:	
	88202	Date: 10/10/2014	Depth increment (in): 12	Sodium Adsorb. Ratio: 0.6	ESP: 0.00
Phone:					

Note: E.C.-Electrical Conductivity or Saltiness, O.M.-Organic Matter, and ESP-Exchangeable Sodium %.

Samp. ID (#)	pH (#)	E.C. (mmhos/cm)	Soil Texture (class)	O. M. (%)	NO_3-N (ppm)	P (Olsen) (ppm)	K(H2O) (ppm)	Mg (ppm)	Ca (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Mn (ppm)	Fe (ppm)
	8.1	1.14	Loam	2.8	6.4	159.0	753.0	501.0	4110.0	144.0	1.9	5.8	5.0	8.9
Crop to grow:	Pasturegrass, Bermuda, established				lbs/ac	P_2O_5 (lbs/ac)	K_2O (lbs/ac)	lbs/ac	lbs/ac	lbs/ac	lbs/ac	lbs/ac	lbs/ac	lbs/ac
Yield Goal:	6.5	t/ac			109	1401	3487	898	7370	258	7	22	19	34



Nutrient Recommendation:

	N lbs/ac	P_2O_5 lbs/ac	K_2O lbs/ac	Mg lbs/ac	Ca lbs/ac	Fe lbs/ac	Cu lbs/ac	Zn lbs/ac	Mn lbs/ac
Recommended Nutrient Rate:	193	0	0	0	0.0	0.0	0.0	0.0	0.0
Organic Nutrient Source (Liquid or Solid Manure):	184	196	581						
Irrigation Water Credits (ppm NO_3-N): 1	7								
Other Nutrient Sources (Standing Legume Crop.):									
Supplemental Nutrient Rate:	1	0	0	0	0.0	0.0	0.0	0.0	0.0
Available Nutrients >= Crop Requirements:	NO	Caution P	Caution K	NO	NO	NO	NO	NO	NO

General Note: Apply P2O5 & K2O in the spring, if needed. Split fertilizer N applications to coincide with harvest regrowth. Consider slow release N for improved efficiency. Follow good Irrigation Water Mgt.

Specific Notes:

Salinity Rating	Very Low	Gypsum Rate (100% pure): 0 lbs/ac or 0 $lbs/1000ft^2$		#N/A	
Salinity not an issue.	Suggested Fertilizer Blend	3 lbs/ac	Urea 45% N	308.1 lbs Total Needed	
	Total Blend (lbs/ac): 3	0 lbs/ac		0.0 lbs Total Needed	
	Blend Cost ($/ac): $0.73	0 lbs/ac		0.0 lbs Total Needed	
Client Signature:	Planner Signature:	N-P2O5-K2O G 45%	0%	0%	308.1 Tt Blend (lbs)

Fertilizer Cost Note: *Default costs are from NASS and are estimated. Enter actual cost in "Fert Cost" tab. Application cost not included.*