HISTORY OF NRCS PHILOSOPHY

Prior to about 1990, NRCS engineers commonly assumed that the accumulation of manure solids and the bacterial action resulting from a sludge interface would effectively reduce seepage from animal waste storage ponds to an acceptable level. However, research at sites with relatively clean sandy soils demonstrated that although manure sealing was providing some reduction in seepage, that reduction was not as complete as formerly believed. Additionally, the seepage in clean sandy soils apparently allowed formation of nitrates because of the oxygenated environment.

Consequently, NRCS engineers in 1990 developed a design document recommending that animal waste storage ponds no longer be constructed in such soils without special design considerations. These recommendations were based on a permeability test data base developed by NRCS and results of research on the mechanisms of manure sealing. That initial design document was titled SNTC Technical Guide 716. It suggested that if any of 4 site conditions were present at a proposed structure location, that a clay liner or other method of reducing seepage would be used in NRCS designs. A few revisions were made and the document was re-issued in September 1993.

Conditions warranting a liner included the identification of soil having less than 20 percent low plasticity fines. Soils were grouped into 4 broad permeability classes, and guidance on the need for special design measures was included for all groups. Other factors were also considered. The design guidance recommended a clay liner at least 1 foot thick constituted of clay soils with more than 20 percent fines and a PI value of greater than 10. It recommended considering the beneficial effect of manure sealing only if foundation soils had a minimum clay content depending on the type of manure in the pond – 15 percent for hog waste and 5 percent for dairy.

EPA Region 6 subsequently adopted this document in their regulations governing design of animal waste storage structures. After NRCS was reorganized in 1994, the Technical Guide lost its identity because the NRCS no longer had Technical Centers. Additionally, NRCS soil laboratories gathered considerable additional permeability data that provided a better basis for grouping soils. Consequently, to incorporate the newer permeability data and provide more detailed design recommendations, the 716 document was revised considerably and expanded. The revised document was published as Appendix 10D to the Agricultural Waste Field Management in October 1998. Soil Groupings were significantly changed. Group III soils now are required to have a plasticity index greater than 15, whereas the Group formerly specified soils to have PI's greater than 10.

SUMMARY OF APPENDIX 10D DESIGN APPROACH

Appendix 10D should provide the following guidance to NRCS designers:

1. Provide guidance when compacted soil or synthetic liners should be included in the design of an AWSP.
2. Provide guidance on soil types that have inherently high permeabilities. Recommend treatment of these soil types with appropriate additives to provide a limited quantity of seepage from AWSP's designed by NRCS.
3. Provide guidance on soil types that have inherently low permeabilities. Recommend construction techniques for minimizing permeability.
4. Provide a rational method for selecting clay liner thickness and permeability values in an economical manner that reduces seepage to tolerable quantities.
5. Provide guidance on tolerable unit seepage rates from AWSP structures. This topic is discussed in considerable detail in a following section.

RATIONALE OF APPENDIX 10D DESIGN APPROACH

Limiting seepage from an agricultural waste storage pond has two primary goals. The first is to filter any virus or bacteria and prevent their migration to an aquifer or water source. The second is to prevent the conversion of ammonia to nitrate in the vadose zone. Nitrates are very mobile once they are formed by the nitrification process. They can then accumulate significantly in ground water. The National drinking water standard for nitrate is 10 PPM, and excessive seepage from AWSP's could increase the level of nitrates in groundwater above this threshold.

Other important sources of nitrates include the field-applied waste, commercial fertilizers, atmospheric nitrogen, and naturally occurring nitrogen in other native materials. In many documented instances of elevated levels of nitrates, the attributed sources were the field-applied waste or commercial fertilizers, not seepage from AWSP's. Often, poor wellhead protection has contributed to pollution of the well water. The author is not aware of well-documented research where properly constructed, lined AWSP's have been clearly shown to have contributed to elevated nitrate levels in groundwater. A recent summary of a Kansas State Report [1] stated that "Our analysis of well water is limited and on-going, but our sampling indicates no widespread nitrate contamination of groundwater in the vicinity of concentrated animal operations."

Several things explain why nitrate contamination has not been documented at sites where properly constructed clay or synthetic liners were installed. First, NRCS and private engineers have only designed clay and synthetic liners for AWSP's for a relatively short time. Seepage from these ponds should develop slowly, and several years may be required to show the effects of any seepage that may be occurring. Secondly, the seepage in these properly constructed ponds is likely to occur in a relatively anoxic environment. Because nitrification, required to convert ammonia to nitrates, only occurs in the presence of oxygen, nitrate development within clay liners is probably limited.

[1] Kansas State University, "Evaluation of Lagoons for Containment of Animal Waste", April 28, 1998.

Many State regulatory attempts to regulate seepage through clay liners are incomplete, in that they only incorporate one or 2 of the 3 elements that are required to define the seepage rate through a liner. NRCS developed a design approach that incorporates all of the elements, based on Darcy's law governing seepage.

Three elements govern the amount of seepage through a clay liner, as follows:

1. The coefficient of permeability of the clay liner
2. The head of liquid in the pond
3. The thickness of the clay liner.

For a unit area of pond bottom, the amount of seepage, defined in Appendix 10D as specific discharge, ν is as follows:

$$\nu = \frac{k * (H + d)}{d}$$

Defining an acceptable seepage rate is not a simple task. Appendix 10D recommends an allowable seepage quantity that is based on an historically accepted tenet of clay liner design – which is that a coefficient of permeability of 1×10^{-7} cm/sec is reasonable and prudent for clay liners. This value, rightly or wrongly, has a long history of acceptability in design of impoundments of various types, including sanitary landfills. The other components defining an acceptable seepage quantity are based on typical NRCS designs – one with ponds having a depth of water, H, of about 9 feet, and a liner thickness, d, of 1 foot. Substituting these values in the above equation obtains an implied acceptable unit seepage rate of 10^{-6} $cm^3/cm^2/sec$.

Research is available indicating that seepage is reduced by at least 1 order of magnitude (a factor of 10) by the accumulation of manure solids and bacterial action. An Appendix to this report summarizes these 4 articles and their conclusions. NRCS guidelines accept this research and allow designers to design based on an increased initial seepage rate of 10^{-5} $cm^3/cm^2/sec$. This assumption presumes that shortly after the pond fills, seepage will reduce to the target value of 10^{-6} $cm^3/cm^2/sec$. The assumption is assumed valid by NRCS for soils with a minimum clay content of 5 percent for dairy waste and 15 percent for hog waste.

Several states have adopted a similar approach to limiting seepage from AWSP's. For example, Nebraska has a maximum seepage rate requirement of ¼ $in^3/in^2/day$, which converts to 7.3×10^{-6} $cm^3/cm^2/sec$. This rate is about ¾ of the acceptable seepage rate defined in the NRCS guidelines. Specified values for acceptable seepage vary from as low as 500 gallons/acre/day to 6,790 gallons per acre per day (1/4"per day).

One problem with this approach to designing clay liners is that the approach considers only unit area seepage. The same criterion applies for small and large facilities. In the absence of information from research providing more detailed information on the impact of seepage through clay liners, however, more detailed design procedures do not appear justified at present, in the opinion of the author.

PRACTICAL APPLICATION OF APPENDIX 10D DESIGN APPROACH

The procedures in Appendix 10D to the Ag Waste Management Field Handbook provide a rational approach to selecting an optimal combination of liner thickness and permeability to achieve a relatively economical but effective liner design. It recognizes that manipulating the permeability of the soil liner is the most cost effective approach in most cases. While clay liners obviously allow some seepage, it appears that the limited seepage from a properly designed site will have minimal impact on groundwater quality. Even concrete or synthetic lined ponds will have some leakage because of defects in the liner itself or seams in the liner.

If designers of AWSP's don't have the flexibility of considering a clay liner, the only alternative in the author's opinion is to specify synthetic liners such as HDPE, EPDM, or GCL's. NRCS has significant expertise in the selection, specification, and construction of sites using these products in addition to clay liners. NRCS developed and it presently conducts a 1-week course on the topic of geo-synthetic liners for AWSP's.

NRCS engineers examined a variety of research studies in formulating their guidance on animal waste storage ponds in the early 1990's. They were assisted by other experts such as Texas A&M Extension Service's Dr. John Sweeten. Based on their literature review, the NRCS engineers concluded that the reduction in predicted seepage when manure is added to the storage ponds is equal to at least one order of magnitude.

Four of the primary references studied were as follows, with a summary of findings after each listed reference.

1. Miller, M.H., Robinson, J.B., and R.W. Gillham. "Self-Sealing of Earthen Liquid Manure Storage Ponds: I. A Case Study." Journal Environmental Quality, Volume 14. No. 4, 1985, pp. 533-538.

    This study involved a large lagoon constructed to store waste from a 4,500 head beef cattle operation. The lagoon was constructed by extending a dike across a depression. The dike was about 5 meters high and 100 meters long. Soils at the site were glacial outwash sands with clay contents typically about 20 percent.

    Monitoring wells were installed around the site and chloride, nitrate, and ammonia were monitored after introduction of the manure into the pond. Researchers noted a marked reduction in seepage within 4 weeks of introduction of the manure into the pond. The infiltration rate decreased to at least 10^{-6} cm/sec within 12 weeks of the manure introduction.

    Monitoring wells showed that concentrations of chemicals often became more dilute because lateral groundwater flow was greater than leakage from the manure pond, and significant dilution occurred.

    Some decrease in nitrate nitrogen was observed and attributed to denitrification in the groundwater zone.

2. Roswell, J.G., Miller, M.H., and P.H. Groenevelt. "Self Healing of Earthen Liquid Manure Storage Ponds: II. Rate and Mechanism of Sealing." Journal of Environmental Quality, Vol. 14, No. 4, 1985, pp. 539-543.

   This was a laboratory study of soil cores from the same site as studied in the previous article. Permeability rates in clay cores reached 10^{-6} cm/sec permeability when subjected to manure within 3-10 days. Cores of loam and sandy loam reached infiltration values of 10^{-6} cm/sec in about 50-60 days. was The primary mechanism of sealing is physical blocking of the soil pores, in the opinion of the researchers. Biological action was not a major contributor to sealing.

3. Barrington, S.F. and R.S. Broughton. "Designing Earthen Storage Facilities for Manure." Canadian Agricultural Engineering, Vol. 30, pp. 289-292. 1988.

   These researchers reviewed 8 years of background material on sealing mechanisms. Background papers included articles by Jett, 1974, Chang, 1975, Miller and Robinson, 1981. Conclusions are that reduction in seepage by manure sealing is reliable provided soils have a minimum clay content. They conclude that in order to achieve infiltration rates in the order of 10-7 cm/sec, that soils should have clay contents of 5 percent for dairy waste and 15 percent for hog waste.

   The researchers further conclude that despite reducing infiltration to 10-7 cm/sec, that seepage still poses a contamination hazard for the immediate groundwater. They suggest soils with a cation exchange equivalent of at least 30 be specified for clay liners in animal waste storage ponds. For the soils studied, this value of CEC would correspond to a minimum clay content of about 30 percent.

4. Barrington, Suzelle, and Pierre Jutras. "Soil Sealing by manure in Various Soil Types." ASAE, Paper No. 83-4571. 1983.

   These researchers investigated soil sealing by both swine and dairy manures. Four reservoirs about 9 feet deep were filled with dairy manure that was about 6.5 percent solids. Three of the lagoons were in clay, loam, and fine sand. The fourth lagoon was in 4 feet of sand over clay. Infiltration rates were initially high but dropped to from 1 to 3 x 10-6 cm/sec within two weeks. A year later the rates were similar.

   Additional study of manure sealing was conducted in the laboratory. The authors recommended soil particle sizes for manure sealing as follows. Swine slurries would require a fine sand with a minimum clay content of 10 to 15 percent while dairy would only require a content of 3 percent, assuming homogeneous soils. These researchers also recommended that soils in the boundary of lagoons have a minimum clay content of 30 percent to furnish more adsorption of contaminants.

Background on modification of Tech Note 716

Tech Note 716 was developed to provide a rational design for clay liners at the time when there was no guidance available. It was obvious that writers of criteria for other purposes were not rationally considering the effects of the criteria, but using rather arbitrary values for elements of a design. NRCS engineers who developed SNTC Tech Note 716 recognized that the laws of soil mechanics dictated that a significant, quantifiable seepage would occur through a clay liner. Based on Darcy's law, it was recognized that there are 3 elements dictating flow – the head in the reservoir, the thickness of the liner, and the k value of the liner.

Tech Note 716 was developed based on a single premise that seemed to be acceptable to EPA regulators in particular – that a k value of 10^{-7} cm/sec was a desirable target for compacted soil liners. The hope was that if NRCS could demonstrate a process that was rational, that criteria that are more stringent might be avoided, such as an arbitrary thickness criterion. For example, in some sanitary landfill clay liners, a minimum thickness of 4 feet was common. The premise behind 716 then was that if 10^{-7} cm/sec was an acceptably low permeability, one could use other elements of a common, reasonably minimal design used by NRCS and that the resultant specific discharge would be acceptable to regulators. It was never based on any measurements of permeability or contaminant plumes.

The reasonably minimal design defined was a 7-feet deep lagoon and a 1 foot deep clay liner. This was used to define a specific discharge that would perhaps appear reasonable to regulators. From the definition sketch, the hydraulic gradient then was 8:1. A specific discharge of 0.028 ft^3/ft^2/day was obtained by using a k value of 10^{-6} cm/sec (assuming that a one-order of magnitude reduction in seepage may occur because of manure sealing and that the final permeability would then be 10^{-7}), and a hydraulic gradient of 8. Because the hydraulic gradient of 8 was used in the development of the criteria seepage rate, the developers of 716 considered it as part of the criteria.

As NRCS began helping with larger projects where the depth of water was considerably greater than 7 feet, it became apparent that this was a problem. Liners as deep as 3 and 4 feet were being required solely by this criterion. Once an allowable specific discharge value was arbitrarily defined, the additional limitation of a hydraulic gradient of 8 or less became superfluous, in my opinion. Because it is much more economical to limit seepage by reducing the coefficient of permeability than it is by increasing the liner thickness, this criteria was a real hindrance to sensible design. Theoretically on its own merits, it made no sense. There is no significant difference in the performance of a 1-foot thick liner than a 2-foot thick liner, if the coefficient of permeability is made half as large. In other words, a 2-feet thick liner is not inherently more safe than a 1-foot thick liner if properly constructed. In essence, this is what the hydraulic gradient criterion says.

The requirement that a liner not be placed on a soil into which it could pipe addresses any questions on a permissible gradient. Lab tests in Lincoln show that even very large gradients cannot induce piping if the two soils involved are filter compatible.

DEPTH OF MANURE SEALING INTO LINER

Several references detail observations on existing ponds that were emptied and then excavated to examine the "manure seal". One was a study of dairy waste lagoons in New Mexico. This study attempted to measure the permeability of the manure seal using a falling head permeability field test. The basic information from that study was that there are two basic layers of manure. The first is a green fibrous material they call layer A. It may be as much as several feet thick in an old pond, and is probably not effective in reducing seepage. The other layer is a black layer underneath, called layer B. It is thought to be a product of anaerobic digestion of either the organic matter in layer A or of manure that was initially mixed into the top soil prior to construction of the pond. The black layer was observed to be about two inches (5 centimeters) thick. It is thought by these investigators to be the portion of the liner that is effective in reducing seepage. The estimated conductivity of manure liners in this study is estimated to be a median value of 7×10^{-4} feet day (2.5×10^{-7} cm/sec). The estimated range in permeability of the manure liners was from 1.1×10^{-4} ft/day (3.9×10^{-8} cm/sec) to 3.4×10^{-2} ft/day (1.2×10^{-5} cm/sec).

The second reference is from an NRCS study of an abandoned lagoon in New York. The paper was presented at the 1998 ASAE conference in Orlando. That study shows observations similar to those in New Mexico. A surface layer of fibrous material is underlain by a thin black film. This is typical of a situation where gleization has occurred.

The permeability that would be result in a combined permeability of the manure seal and a 1-foot thick liner theoretically is examined as follows:

In the background for SNTC Tech Note 716 and the subsequent Appendix 10D, one assumption is that biological sealing on certain soils will result in a 1 order (1/10) reduction in the effective permeability of a clay liner. Following computations show what the theoretical permeability of an assumed 0.15 foot (4.6 centimeters) thick layer of biological seal on top of the 1 foot thick clay liner would have to be for this assumption to be true.

First, the equation for converting the overall permeability of a layered system when flow is perpendicular to the bedding planes of the layered soils is from Terzaghi and Peck, 2nd edition, page 56,

$$k_{avg} = \frac{H}{\frac{H_1}{k_1} + \frac{H_2}{k_2}}$$

Next, assume that the effective permeability, k_{avg} after biological sealing is to be 0.0002835 ft/day (1×10^{-7} cm/sec). Assume that the permeability of the second layer, the clay liner is 0.002835 fpd (1×10^{-6} cm/sec), and that the clay liner is 1 foot thick. Assume that the biological seal (layer number 1) is 0.15 foot thick, and determine from the above equation what the permeability of that layer would have to be:

$$0.0002835 = \frac{1.15}{\frac{0.15}{k_1} + \frac{1.0}{0.002835}}$$

Substituting and solving, then, k_1 equals 0.0000405 ft/day (1.4 x 10^{-8}) cm/sec.

In summary, to achieve a composite permeability of 1 x 10^{-7} cm/sec, you could have a 1 foot thick clay liner with a k value of 10^{-6} cm/sec overlain by a 0.15 foot thick layer of manure seal that has a k value of 1.4 x 10^{-8} cm/sec, and you would have a composite permeability of 10^{-7} cm/sec.

A k value for the manure seal of 1.4 x 10^{-8} appears reasonable, especially considering the results of the New Mexico study. I am not sure how much other research is available on the k value of the gleization layer. I assume that the original NRCS assumptions portrayed in SNTC Tech Note 716 were premised on measurements of actual total seepage volumes from impoundments, rather than attempting to measure this on a micro/scale.

DEVELOPMENT OF ALLOWABLE SPECIFIC DISCHARGE CRITERION

The specific discharge derivation was based on a typical NRCS design assuming a 1 foot thick layer of soil that had a k value of 10^{-6} cm/sec that would be reduced by an order of magnitude with manure sealing. It was an attempt to provide some design guidance to arrive at a reasonable, achievable design that would be protective. There is limited basis for the absolute safety of this guidance. It doesn't consider the size of the lagoon and other important factors. The nitrate contribution to groundwater is probably much greater from the field application of both manure and commercial fertilizer than from leakage out of animal waste storage ponds. The likelihood is that anaerobic conditions occur at least within the clay liner, and without oxygen, nitrification can't occur.

Another way of examining and protecting ground water contamination is to look at well head protection areas. Web sites with information on wellhead protection include:

The URL is http://www.epa.gov/OGWDW/Pubs/03ground.html.

Another is http://deq.state.wy.us/wqd/consourc.htm .

One more is http://www-wwrc.uwyo.edu/wrds/deq/whp/whpsect2.html