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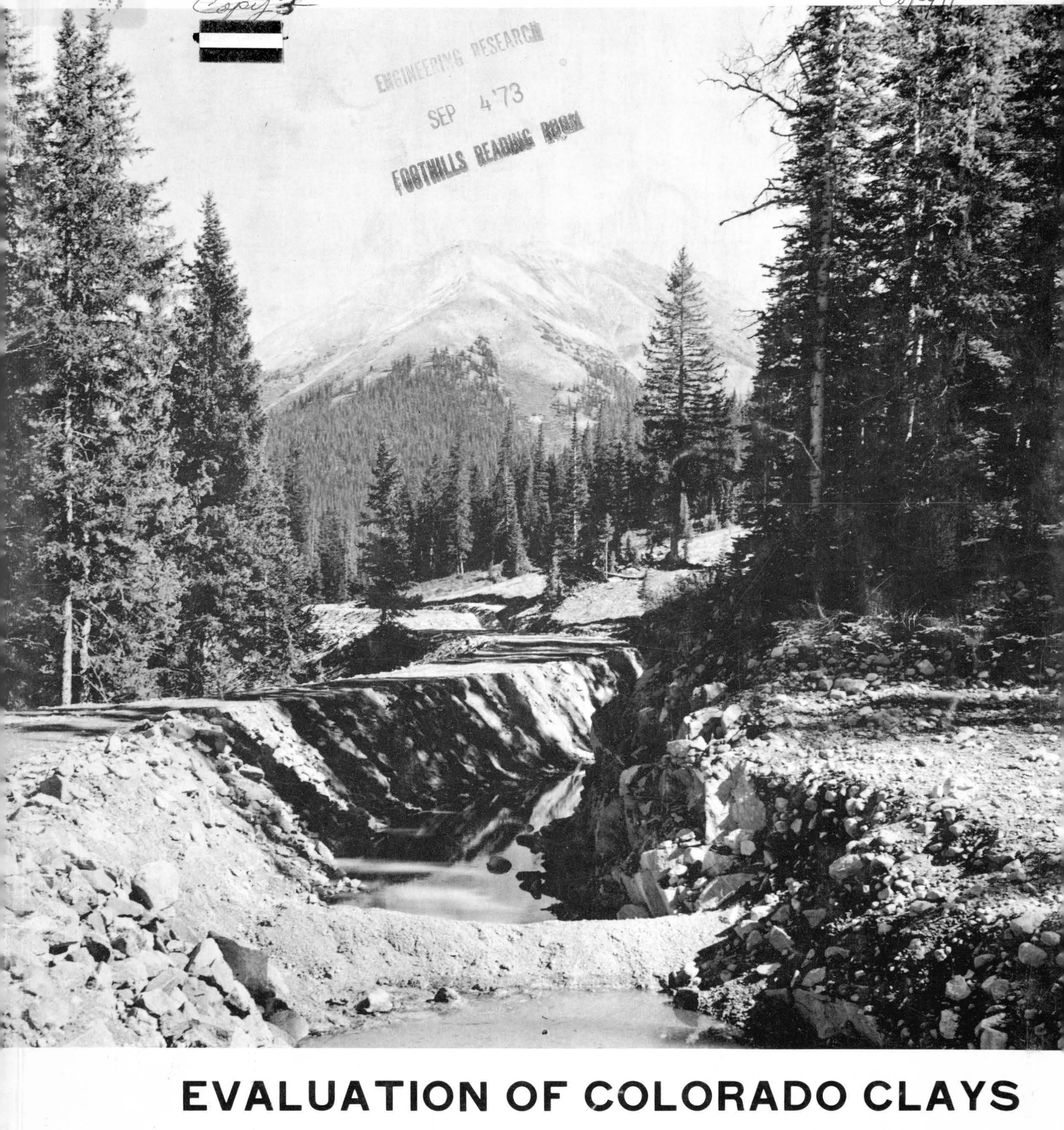

EVALUATION OF COLORADO CLAYS FOR SEALING PURPOSES

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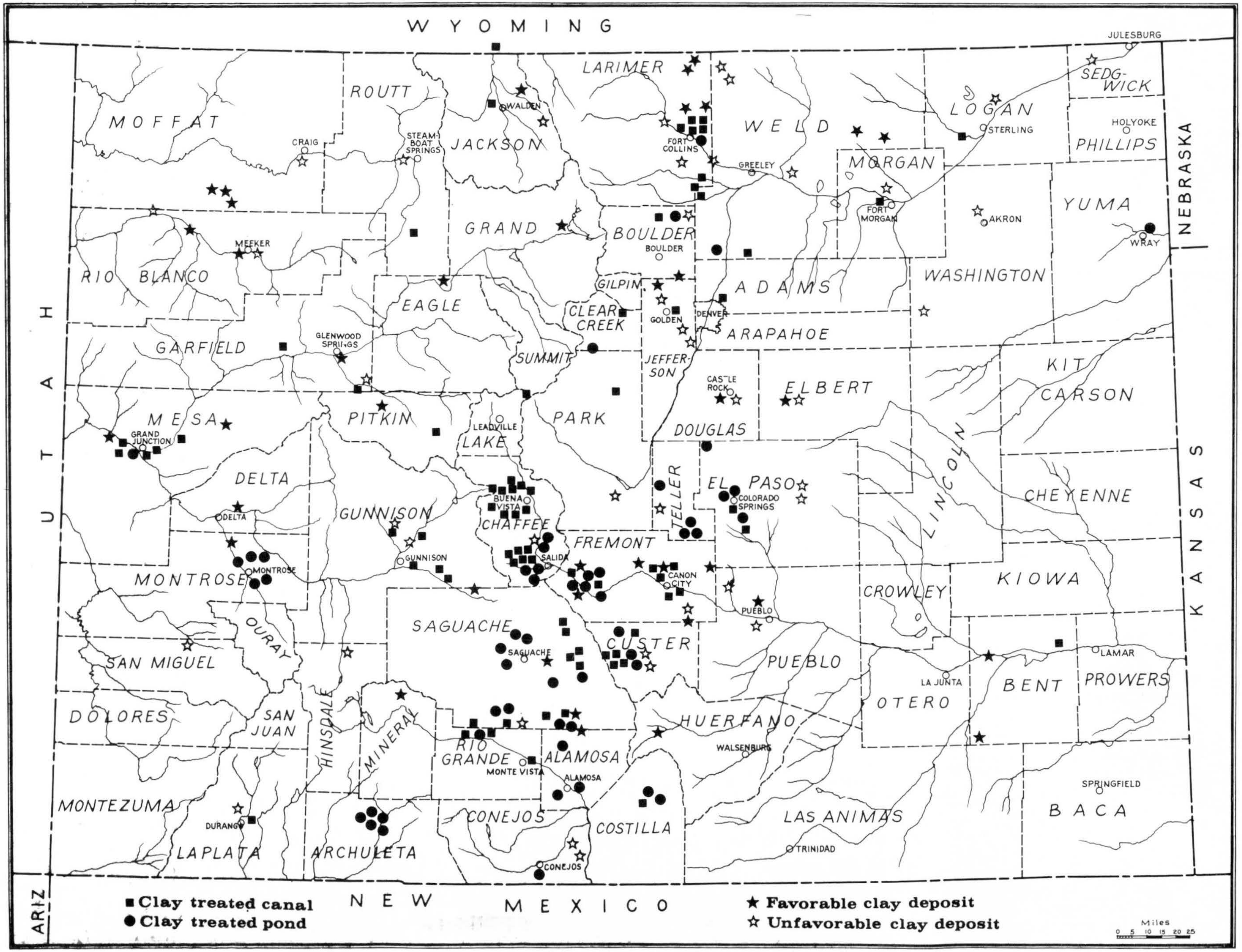

FIGURE 1

ACKNOWLEDGMENTS

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EVALUATION OF COLORADO CLAYS FOR SEALING PURPOSES

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ADVANCE SUMMARY

Work on canal and pond sealants was started at Colorado State University in 1953. The current study, started in 1960, relates to the possibilities of using Colorado clays for sealing purposes.

The early part of the current study involved sampling and laboratory evaluation of clay deposits located throughout Colorado. The later phases of the study involved field trials designed to evaluate clays as sealants for Colorado canals and ponds. In addition, commercial development of suitable deposits has been encouraged.

For the convenience of the busy reader, the results of the work are summarized in this section. The summary provides information on clay specifications and clay sealing methods. The section on Evaluation of Field Installations provides the supporting data concerning methods of application. The supporting data for the clay specifications is in the section on Evaluation of Clays.

Of the many materials used in canal and pond sealing work, the clays are commonly the lowest in cost since they are available locally in many areas. They are also the most misused and misunderstood of the sealing materials. This report gives information pertaining to the design and control of clay application for sealing purposes.

The evaluations of this study, pertaining to 321 samples of clay and 132 clay installations in canals and ponds, indicate the major problems in the use of clays as sealants are:

1. In lack of locally developed clay deposits suitable for sealing purposes in canals and ponds.

2. Inadequate preparation of site prior to sealing operation.

3. Inadequate design and construction control.

4. In lack of good follow-up maintenance.

Favorable Locations for Clays

The wide variety of Colorado clays makes it difficult to generalize on the appearance and occurrence of clay (or bentonite) suitable for sealing purposes. Briefly, the best clays are commonly found in deposits with the following features:

1. Found in badland areas -- The outcrop areas of deposits usually are bare of vegetation.

2. Outcrop clay granular or gummy -- When dry the exposed clay is commonly loose and granular (like coarse sawdust) and when wet it is usually extremely gummy and slick.

3. Various colors -- The clay is found in many colors with red, green, yellow and white most common.

4. Several geological formations -- The most common geological formations in which the clays occur include the Morrison, Benton, Mancos, and recent Tertiary formations.

5. Various types of deposits -- Almost all of the best deposits of Colorado clays have occurred in either Tertiary volcanics and their derivatives or older sedimentary formations, such as the Morrison formation of Jurassic age. Some acceptable clays, however, are found in other types of deposits, such as recent lake bed deposits.

Whether the material under consideration for sealing purposes is called silt, clay or bentonite, it must obviously be water-tight or impermeable to be satisfactory. This characteristic is easily determined by laboratory testing.

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[1] Project leader and [2] assistant civil engineer, Civil Engineering Section, Colorado Agricultural Experiment Station, Colorado State University.

Tentative Specifications

Tentative specifications for three general types of sealing clay are listed below:

Test	Type I Clay* High-swell bentonite	Type II Clay* Low-swell bentonite	Type III Clay** Wash-in clay
Layer permeability	0.005 ft./day or less	0.005 ft./day or less	0.005 ft./day or less
Filter permeability	10.0 ml./min. or less	10.0 ml./min. or less	10.0 ml./min. or less
Free swell	600% or more	50 to 600%	- - -
Mix index	- - -	- - -	40% or more
100% passing	3/8-inch screen	3/4-inch screen	1-inch screen
Moisture content	15% or less	20% or less	20% or less
Colloidal yield	50% or more	40% or more	30% or more
Grit content	10% or less	20% or less	30% or less

*Used mainly for layer applications
**Used mainly for wash-in applications

These specifications were developed in cooperation with the Soil Conservation Service and the Agricultural Stabilization and Conservation Service in Colorado. They may require modification for extreme conditions such as sealing open rocky materials where extra amounts of grit or sand-size particles may be required for satisfactory sealing. Additional experience may also indicate the need for modifications at a later date.

In comparing the various clays used in the Colorado canal and pond sealing work with the specifications outlined above, two conclusions apply:

1. Virtually all suitable Colorado clays tested in this work are of Type II or III. Few, if any, of the Colorado deposits will consistently yield Type I clay.

2. A Wyoming bentonite of drilling mud quality (90 bbl yield or more) will usually qualify as a Type I clay.

Clay Producers

A tentative list of clay producers is outlined below:

River basin	Name	Deposit No.	Town	Type
North Platte	Colter	S-89	Walden	II
South Platte	Munroe	S-33	Fort Collins	II*
	Conda	S-37	Marshall	III
Arkansas	Lamberg	S-49	Salida	III
	Kessler	S-34	Canon City	III*
	Dilley	S-28	Canon City	III
	Stough	S-44	Las Animas	II
	Butterfield	S-44	Las Animas	II
Rio Grande	Cowan	S-40	Mosca	III
San Juan	Flora	S-101	Durango	II*
Colorado	Rump	S-42	Grand Junction	II
	Redlands	S-42	Grand Junction	II
	Kelley	S-113	Grand Junction	II
	Wells	S-42	Fruita	II*

*Tentative classification – information regarding extent and character of deposit is incomplete.

Quality Control for Clays

The major quality control problems, such as high moisture content, variability of clay, and oversize lumps of clay, can be controlled satisfactorily, in most cases, by the following:

1. Exploration -- Before opening a clay pit, explore and classify the clay materials by test drilling or trenching, representative sampling, and comprehensive testing of the samples.

2. Pit operation -- Remove overburden from a large, south-sloping area of the deposit (in excess of one acre, if possible) and harrow inplace clay during dry weather. This will promote air drying and breakdown of clay lumps.

3. Stockpiling and Screening -- Stockpile the clay after air drying, remove from stockpile so as to obtain maximum mixing of clay, and process the clay through a 3/4-inch screen (or smaller) before marketing. In many cases, the nonclay materials will be concentrated in the material rejected by the screen.

Preliminary Preparation of Canal or Pond Site

Prior to the clay sealing work, the leaky canal or pond should be cleared of vegetation and other debris, and the eroding areas protected with gravel or riprap. Inadequate site preparation is a common failing of many of the installations evaluated. Inadequate erosion control is also a common problem, especially in canals and ponds situated in fine materials, such as sandy to silty soils. A stable channel in canals and beach line in ponds is vitally important to long life of clay sealing.

Clay Sealing Methods

Site conditions vary widely, thus, the installation methods also vary. The most common clay sealing methods are:

1. Wash-in method -- Clay is washed into flowing water at head end of canal section to be sealed.

2. Multiple-dam method -- Clay is washed into water from dams spaced at regular intervals in canal section to be sealed.

3. Pure membrane method -- The canal or pond section is overexcavated at least 6 inches, the clay membrane and its protecting cover is then placed.

4. Mixed layer membrane method -- The clay is mixed and compacted into the top 3 to 6 inches of the subgrade materials of the pond or canal.

In general, the wash-in and multiple-dam methods are best suited for sealing coarse materials, such as fractured rock, gravel, and coarse sand, whereas the membrane methods are best for fine materials, such as fine sand and sandy silt.

One major exception to the above arises when the canal or pond water is hard (high in calcium and magnesium) or high in salts.[3] Wash-in methods should not be used in hard or salty water areas.

Suitable sealing clays are usually sodium clays; they are almost always 10 percent or more sodium-saturated. When a sodium clay is mixed into hard water, it will be changed immediately to a calcium clay. When a calcium clay is deposited in the leaky zones of the canal or pond, it will be much less effective as a sealer than its sodium counterpart. The use of a dispersing agent, such as sodium tripolyphosphate, will temporarily control the changing of sodium to calcium clay but will not stop the reaction permanently if the normal canal or pond water is hard.

In hard water areas, it is best to place the clay as a compacted and covered material rather than as a sedimented or wash-in material. This is also true for salt water areas.

Sealing of Coarse Materials

This study indicates the sealing of coarse materials is best accomplished with the wash-in methods except in areas where the water is high in salts or hardness. The membrane methods may be used, but in heavy rock sections especially, overexcavation of the section is expensive and mixing of the clay into a rocky subgrade material is not usually feasible. The stability of channels in coarse materials is usually excellent. Furthermore, the seepage rate is usually high. Thus, immediate benefits of clay sealing in coarse materials are commonly of a much higher magnitude and frequently last much longer than those for treatments in fine-grained soils.

Coarse materials with fines -- Under ideal conditions, the coarse materials of the channel or pond bottom and sides have an increasing content of fines with depth. With this condition, the clay sealing takes place beneath the surface on the finer-grained materials and is protected by the coarse grained materials of the surface layer. This ideal condition is not unusual in mountainous areas where coarse materials are prevalent and where, with time, the flowing canal water removes the fines from the surface layer, leaving a plating of coarse gravel, cobble or rock. Owing to wave action, the same condition will develop along the shoreline of some ponds in coarse materials. Sealing produced with the wash-in methods under these conditions is protected from erosion and, to some extent, from the disturbing actions of freezing and drying.

Coarse materials without fines -- If the coarse material lacks the necessary fines in depth, the sealing clay, when washed into place may, penetrate but will not stop or seal. In this case, as in canals traversing rock talus slopes, the intermediate particle sizes in the silt and sand range are needed as bridging agents. They must, therefore, be furnished along with the sealing clay during the wash-in procedures to produce an adequate sealing action. Wet sawdust has been used successfully as the bridging or void-plugging agent in remote alpine areas where sand- and silt-size materials are not readily available.

In extremely open rocky zones, and prior to the wash-in work, it may be advantageous to fill the large holes and crevices in the bottom and banks with a mixture of clay and a sandy silt filler material. Use one part Type I, II or III clay with five to ten parts of a filler soil, such as a sandy silt; then followup with a wash-in treatment with an acceptable clay (Type III).

Amount to use -- The type and amount of clay needed to produce an acceptable seal will vary with conditions. However, in most coarse materials, a Type III clay is best. The amount used in past installations has varied from 9 lbs./sq.ft. of canal or pond area in coarse open materials to 1 lb./sq.ft. as a minimum for coarse materials with considerable fines.

Sealing of Fine Materials

This research work emphasized development of wash-in methods for sealing coarse materials and not much work was done on clay sealing of fine materials, such as fine sands and silts. The available experience, however, indicates several conclusions:

1. The best methods for using clay in sealing fine materials are the membrane methods; both mixed layer and buried layer in either canals or ponds.

2. The wash-in methods are not recommended for use in fine materials, except perhaps where the fine materials are protected with gravel or rock riprap and where the wash-in clay can penetrate into the riprap layer.

3. A cover layer of riprap is required on membranes--both mixed and pure layer--in areas subjected to high water velocities, cutting by waves, wading or burrowing animals, fluctuating water depth, or active root growth.

4. Accurate measuring of seepage losses from canals in fine materials, before and after clay sealing, is usually a difficult and expensive problem. Seepage losses into fine materials are often

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[3] *According to McNamee (32)*, the upper limit of salt content is 400 ppm total salts or an electrical conductivity of 625 micromhos.*

**Numbers in parentheses refer to Literature Cited on page 35.*

about the same size as the errors of measurement methods, commonly in the range of ± 5 percent.

5. Chemical methods of sealing fine materials show promise and seem worthy of intensified research.

Amount to use -- The type and amount of clay needed to produce an acceptable seal will vary with conditions. In general, the minimum application rates for fine materials are as recommended below:

Leaky soil	Method recommended	Min. application rate
Clay	Buried pure membrane	1.0 lbs./sq.ft.*
Sandy silt	Mixed blanket	1.0 lbs./sq.ft.*
Silty sand	Mixed blanket	1.5 lbs./sq.ft.*
Clean sand	Mixed blanket	2.0 lbs./sq.ft.*

*Type I or II clay – as a powder or as granules (up to wheat size).

To assist in the layer application of clay, the following information may be helpful:

Application rate	1bag(100 lbs.)/square	Approx. thick. of layer	Approx. tons/acre
2 lbs./sq.ft.	7 ft. by 7 ft.	5/16-inch*	44
1.5 lbs./sq.ft.	8' 2'' by 8' 2''	1/4-inch*	33
1 lb./sq.ft.	10 ft. by 10 ft.	3/16-inch*	22

*Coarse granular to lumpy grades of clay can be used but cannot be spread in layers this thin.

Follow-up Maintenance

The need for this type of work is frequently overlooked or disregarded. Follow-up work is needed especially when there is: erosion or undercutting of banks; movement of bed sand along bottom (of canal as dunes); burrowing or rooting by animals, such as crayfish, earthworms, muskrats, pigs, raccoons, etc.; growing of plant roots (or rotting of roots when plants are killed by spraying); and careless cleaning of sealed canals and ponds.

In general, clay-sealed ponds and canals in coarse materials will require less maintenance than those in fine-grained soils, but in any case repeat or follow-up treatments are recommended.

The best time for the repeat treatments in gravelly to rocky canals is in the spring, added to the first water into the dry canal. A treatment consisting of 10 percent of the original amount of the clay treatment is the usual rule-of-thumb guide for the follow-up work. This requires changing to fit the canal conditions, and in some cases retreatment each year may not be needed. Maintenance work in ponds is best accomplished when the pond is dry or at its lowest water level.

Costs to Benefits

Of the various jobs evaluated, the most favorable ratios of costs-to-benefits from clay-sealing were found in the mountainous areas of Colorado. Here it is common to encounter canals that show a 50 to 100 percent loss late in the summer, at a time when water is most needed. In these areas, conditions may be unfavorable for conventional canal (and pond) linings for several reasons, such as high construction costs, frost action, etc. Rocky to gravelly materials with high seepage losses are common in such areas and benefits of clay-sealing may be immediately and strikingly noticeable.

Several installations were noted where a 100 percent loss occurred late in the summer and where clay treatment made deliveries of water possible. In some instances, the costs of sealing were recovered by benefits during the first season following the clay treatment.

Because losses into fine grained materials are commonly much lower than for coarse grained materials, it generally takes a special set of conditions to produce a short term pay-out of costs by benefits. For example, in an irrigation system where short supplies of water place a high value on the late summer water--and especially where intermittent operation is required--clay-sealing with the first water into the dry canal may save sufficient water in 1 or 2 days of operation to pay for the clay.

New Research Needs

One research and development need indicated by this work, relates to the use of water-borne chemicals for sealing canals and ponds situated in fine grained materials. The use of chemicals for sealing, such as sodium chloride (NaCl) and sodium carbonate (Na_2CO_3), is, of course, not new but dependable design and installation procedures are needed.

INTRODUCTION

Seepage loss from canals and reservoirs in Colorado is a serious problem. It is estimated this loss totals about 2,500,000 acre-feet per year. In this research involving 132 canal and pond sites, canal losses ranged from 100 percent (or total loss) in some systems late in the summer to one outstanding minimum loss of less than 3 percent in 8 miles of a relatively large unlined canal. Pond losses ranged from as high as total loss overnight to a minimum of about 1-inch drop in water level in 24 hours.

The above losses are total losses consisting of not only seepage but also evaporation from water surfaces, transpiration from water-line plants, and miscellaneous leakage. Seepage usually is the major part of the loss (1, 2), except perhaps in large relatively-shallow reservoirs where evaporation may be dominant.

In most cases, the seepage loss is not a permanent loss. Water seeping from canals and ponds may serve as a major source of recharge water for nearby wells. Also part of the water may reach the main river channel as return-flow supplementing the water supply for downstream water users. Usually, however, the disadvantages of seepage losses overshadow the advantages. Part of the seepage water may be lost by evaporation and transpiration from nearby seep-damaged areas. Soluble salts may be concentrated in the seep areas and in the water draining from the seep areas. Perhaps the most serious problem, however, is that the water lost as seepage is seldom available for use by those who originally stored and diverted it.

Seepage Control Practices

Although seepage problems are widespread in Colorado, relatively little seepage control of a direct nature, such as canal and pond lining, is being accomplished. This is especially true of the larger supply canals. In some areas of Colorado, considerable concrete lining work is being accomplished in the small on-farm ditches. In some areas, indirect methods of control, such as drainage ditches and tile lines, are utilized widely, but drains do not reduce and, in fact, generally tend to increase the amount of seepage loss from nearby canals and ponds.

Apparently, cost is the main deterrent to the widespread use of canal and pond linings. For example, using an average cost of concrete of $2.50/sq.yd. (unreinforced--3- to 4-inch thick) (3), costs per mile of canal may be estimated as follows:

Large canal (100 ft. wetted perimeter)	$150,000/mile
Small canal (10 ft. wetted perimeter)	15,000/mile

Thus, the cost factor can assume work-stopping proportions when applied to the miles of canal that need lining in any given area or district.

In summation, the need for comprehensive programs of canal and pond lining or sealing is readily evident in many, if not all, of the irrigated areas of Colorado. Financing of the needed work is a common but not insurmountable problem. This problem is being approached in several ways. One method involves Federal loans (USBR) or cost-sharing (ASCS and SCS) for installation of time-tested linings or sealings. Another method relates to research and development programs aimed at reducing the costs of linings and sealing--while maintaining an acceptable level of sealing efficiency.

This report outlines results of investigations into the possibilities of utilizing local clays that are now available at low cost in most areas of Colorado.

Previous Work

Clay has been used extensively in a wide variety of application methods, such as buried membranes and compacted layers (4). It has also been used as a silting[4] material. Since the emphasis of this work is on low-cost methods of application, the silting methods are of vital interest.

As general background, the water supplies of many irrigation projects are changing from intermittently muddy to predominantly clear. This is caused by a variety of conditions, such as the construction of upstream reservoirs that trap sediment. This long-time trend toward a decrease in sediment content causes increased seepage loss from canals, increased scour and erosion of canal bed and banks, increased slumping or sliding of earth slopes below canals, and increased growth of underwater weeds (5, 6).

Silting with various materials has been tried by many irrigation groups, some with outstanding success, but many with little or no favorable results. Best silting results usually have been obtained where the canal bed and bank material is

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[4] *Silting is a catch-all term, meaning the incidental or intended deposition of sediment from water.*

coarse-grained, such as coarse sand, gravel, or fractured rock. Penetration of silt into the coarse materials occurs easily and a relatively long life of seal is obtained provided, of course, that the silting material is watertight. In fine-grained materials, such as silty sand or sandy silt, even the most favorable silting material, such as a high-swelling Wyoming bentonite, will tend to form a surface seal of short life[5] (7-16).

Laboratory flume studies provide useful information on the difficulties encountered in sealing fine-grained bed materials. During investigations by Simons, et al., (17), into properties of water-clay dispersions and their effects on flow and movement of fine bed sand, several observations were made that relate to clay sealing of bed sands:

1. Depth of scour -- The depth of bed movement of fine sands is usually about 20 percent of the flowing water depth--but it may be as much as the depth of flow.

2. Deposition of clay -- Clay tends to deposit at the depth of maximum scour, beneath the drifting sand. Maximum depth of clay burial by sand usually occurs under conditions of maximum water flow and depth.

3. Removal of clay -- Clay deposited beneath the zone of drifting bed material is removed relatively fast when conditions of clear water flow are renewed.

Because of the difficulties in obtaining good sealing results in canals traversing fine-grained materials, most of the silting or clay sedimenting work in this project was concentrated in coarse-grained materials. This introduced several advantages. First, in coarse sand, gravel, or fractured rock, bed sand movement is not usually a critical problem. Secondly, seepage losses (and consequently the need for sealing) are commonly much higher in coarse materials than in fine materials.

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[5] *A comprehensive review, "Clay as a Canal Sealant," by R. D. Dirmeyer will appear in Review Volume II, Division of Engineering Geology, Geological Society of America (scheduled for printing – fall of 1964).*

EVALUATIONS OF FIELD INSTALLATIONS

Evaluation data relating to 132 clay installations in canals and ponds is discussed in this section. This includes 74 canals, 55 reservoirs, and 3 natural streams. Colorado clay was used in all except 13 of the ditches and 3 of the ponds where a Wyoming bentonite (high-swelling) was used.

See Fig. 1 at the front of this report for the approximate locations of installations. The detailed tabulation of evaluations (table 1) is on pages 11 to 14 . The summary information for each site includes location, capacity, wetted area, bed material, installation dates, amount of clay used, method of application, cost, benefits, and followup treatments. The benefits were evaluated by seepage loss measurements or estimates, supplemented by information supplied by the water users.

Since the canal and pond conditions vary widely, a variety of clay sealing methods have been used. Highlights of the major methods are described in this section.

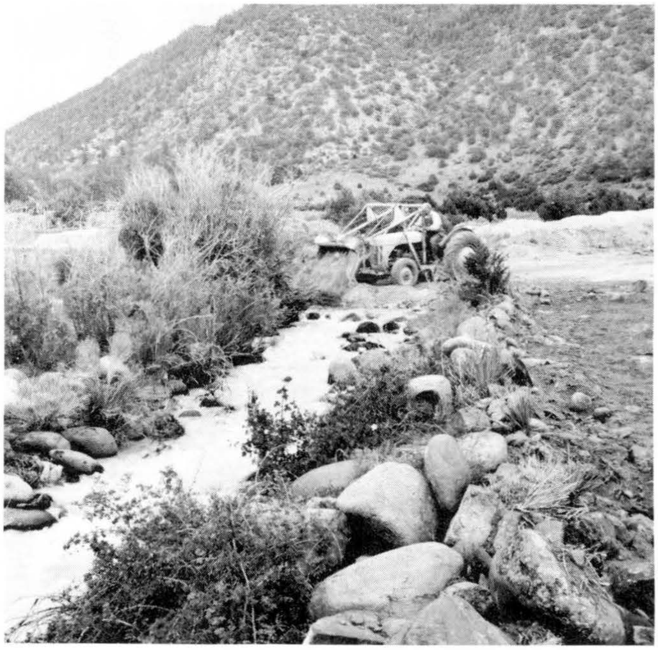

Figure 2.—Clay is washed into the water at the upstream end of the section to be sealed.

Wash-in Method

In this method, clay is washed into the flowing water at the head end of the canal or small pond. The flowing water carries the clay down the canal and into the leaky materials of the canal bed and banks.

This method is especially suited for sealing canals that have steep grades, traverse coarse rocky or gravelly materials, and limited access. As a minimum, the head end of the canal must be accessible to trucks. The best clay for this work has a high mixing index, a low swelling index, and low permeability--both filter and layer.

Major difficulties with the wash-in method relate to inadequate cleaning of canals or ponds before clay treatment, and unstable channels after treatment. Also, good water measurement control before, during, and after a clay installation is helpful but is not easily obtained for many of the ditches where the wash-in method fits best (i.e. steep grade, inaccessible, etc.)

Figures 2, 3, 4, and 5 refer to the wash-in method.

Figure 3.—The milky slurry is carried downstream, sealing where water is lost by seepage.

Figure 4.—Treated channel on right, untreated creek channel on left, Cotton Creek Ditch in San Luis Valley.

Figure 5.—Channel erosion can produce a short life of sealing.

Good data are available for some of the sites. Data concerning the Cotton Creek installation (San Luis Valley) are listed in the following table:

Date	Upper flume*	Lower flume*	Loss	
	CFS	CFS	CFS	Percent
Seepage conditions before initial treatment				
6-14-61	15.0	5.5	9.5	63
70 tons of bentonite washed in at upper end on 6-20-61				
6-22-61	12.0	8.0	4.0	33
An additional 70 tons of bentonite washed in at upper end on 6-26-61				
6-27-61	6.0	4.3	1.7	28
An additional 70 tons of bentonite washed in at upper end on 7-11-61				
7-16-61	12.0	8.7	3.3	27.6
Between 7-11-61 and 10-8-61 a 5 to 10 cfs flow was maintained at lower flume				
10-8-61	8.7	5.3	3.4	39

*Parshall flume

The above data illustrate several points. First, even though several factors, including channel erosion, prevented complete sealing, the partial benefits during the first year were nearly equal in value to the cost of clay treatment. About 660 acre-feet of water was saved during the first year. The cost was about $3,900. The major benefit was the ability to deliver water at the lower end of the system late in the summer where this was not possible before the clay treatment.

Secondly, multiple treatments during initial and followup treatments are feasible both as a matter of cost and of operation. Followup treatments have been completed on this job and, consequently, the seal has been maintained even though the channel erodes during periods of high flow.

A third point is that in some areas the clay sealing methods alone may be sufficient for controlling seepage. The Cotton Creek project has a long history of engineering designs and estimates aimed at solving the water loss problem. None of the schemes were activated because of the high costs involved. The clay sealing is not a complete answer to all the problems of the Cotton Creek Ditch, but it has provided an economically feasible method of saving water.

Multiple-dam Method

This method is used when the ditch section can be reached easily by trucks at most points. It is a wash-in method but has the advantage of being a controlled process of ponding.

Clay is stacked in the dry canal, spaced at regular intervals to obtain full ponding coverage of the normal wetted area of the canal. A small head of water is turned into the canal. The flow ponds behind the first dam, finally overtops it, and the resulting muddy mixture is caught behind the second dam. The same sequence is repeated through the canal reach being treated. The canal water is utilized to carry the clay to and into the leaky zones of the canal bottom and banks.

This method is especially suited for sealing canals that have moderate grades, traverse coarse sandy to rocky materials, and are accessible to trucks. The best clay for this work has a high mixing index, a low swelling index, and low permeability--both filter and permeability.

Major difficulties encountered in this method include those mentioned for the wash-in method (i.e., channel erosion) with the exception that canal cleaning problems tend to replace channel cutting problems as the canal grades become less steep and the canal bed materials less coarse.

Clay penetration also tends to be a problem in the finer grained soils, especially in silty sand soils where the clay commonly will form a surface seal, vulnerable to erosion, drying, cracking, and puncturing. Satisfactory followup maintenance of the clay sealing, which in many instances can be performed at relatively low cost, is also a common major problem.

Figures 6, 7, 8, and 9 refer to the multiple-dam method.

Figure 6.—Dams of clay are spaced along the canal reach being sealed.

Figure 8.—The slurry is ponded behind the next dam downstream and the breakout process repeated.

Figure 9.—Adequate channel cleaning, prior to the clay sealing treatment, is a problem in some instances.

Membrane Methods

There are two general types of membranes: buried membrane and mixed layer membrane.

In the buried membrane method, the canal or pond section is overexcavated at least 6 inches before placing the clay membrane. In the mixed layer membrane method, the canal or pond section is cleaned and shaped, but not overexcavated. In both methods, the clay layer is placed on the leaky areas at 1 lb./sq.ft. (approx. 1/8 inch of finely powdered clay) up to 9 lbs./sq. ft. (approximately 1 inch of coarse granular clay). The actual rate of application varies with the type of canal bed material and the coarseness of the sealing material. Rates are listed in Advance Summary.

In the buried membrane method, the clay layer is covered with the soil previously excavated from the canal or pond section. The loosely placed cover material is packed and protected with gravel or rock riprap where needed. In the mixed layer membrane method, the clay is worked into the top 3 to 6 inches of the underlying soil with a harrow, disk, etc. The resulting mixture is packed to the maximum possible extent and protected from erosion (with gravel, etc.,) where needed. Protection is especially needed at the water line in both canals and ponds.

The mixed layer membrane method is best suited to granular soils (sandy to silty soils) and the buried membrane method is best suited to heavy clay soils where uniform mixing of the clay into the soil would be difficult, if not impossible.

The membrane methods are especially suited for sealing canals that have moderate to flat grades, traverse fine-grained soils, such as fine sands and silts, and are accessible to trucks and other construction equipment. The best clay for this work has a low layer permeability and a high swelling index.

Major construction difficulties include: insufficient use of clay; uneven spreading of clay layer; inadequate protection of membrane from erosion, cracking, puncturing, or cleaning; and inadequate followup maintenance.

Figures 10 to 13 refer to the membrane methods.

Figure 10.—Mixed layer membrane. Clay is spread over the pond bottom and then harrowed into the soil.

Figure 12.—The clay may be placed in the canal in dams and then mixed into the soil with a V-ditcher.

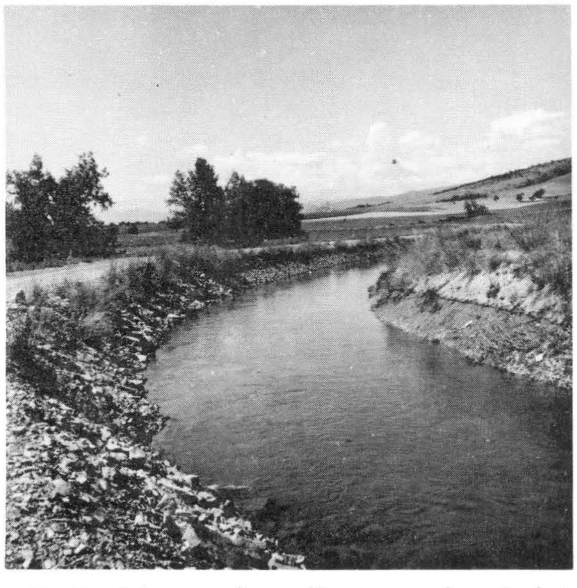

Figure 11.—Mixed layer membrane. Clay is spread on the bottom and sides, disked into soil, compacted, and covered.

Figure 13.—Crayfish burrowing and deep cracking upon drying is harmful to clay sealing.

TABLE I

Sheet 1 of 4

FIELD INSTALLATION DATA

Job Title Location	Capacity Grade	WP* L	Bed Material	Installation Date Amount of Bentonite	Method of Application	Cost	Benefits** and Follow-Up Treatment
				ARKANSAS RIVER BASIN			
Ark. Valley Irr. Canal SW of Buena Vista	20 cfs Slow	8 1400	Rocky-gravelly	July 1961 14 tons (S49)	Multiple-dam	$ 130	Before loss = 22% measured After loss = 17% with flumes (Seal apparently still effective (1962))
Bray Ditch W of Buena Vista	10 cfs Fast	4 15000	Rocky	July 1960 24 tons (S49)	Wash-in	$ 180	Water saved in 1960 produced hay worth $1100 Water saved in 1962 produced hay worth $ 500
W Gate and S Meadow Ditch SW of Buena Vista	8 cfs Fast	4 13000	Rocky	June 1960 28 tons (S49)	Multiple-dam	$ 250	Water saved in 1960 produced hay worth $800; 50% of original seal existed in 1962
Lee Diversion Ditch SW of Buena Vista	4 cfs Fast	3 3000	Rocky	April 1960 25 tons (S49)	Wash-in	$ 225	Before loss = 50% (est) After loss = 10% (est)
Silver Creek Ditch W of Buena Vista	7 cfs Fast	3 16000	Rocky	June 1960 25 tons (S49)	Wash-in	$ 225	Water saved produced hay worth $400 in 1961; June 1962 added 25 tons (S49); seal holding well
Sailor Seep Ditch SW of Buena Vista	4 cfs Fast	3 3500	Rocky	September 1960 24 tons (S49)	Multiple-dam	$ 215	Value of water saved first year equal to cost of bentonite; seal effective in 1962
Esgar Ditch SW of Buena Vista	2 cfs Medium	3 2600	Rocky	June 1960 4 tons (S49)	Wash-in	$ 40	Before loss = 30% (est) After loss = 15% (est) (Seal effective in 1962)
Dry Creek Diversion SW of Buena Vista	2 cfs Fast	2 8000	Rocky	June 1960 20 tons (S49)	Wash-in	$ 180	Treatment brought flow 3/4 mile farther in ditch; September 1962 washed in 13 tons (S49) -increased flow
Cottonwood Creek W of Buena Vista	300 cfs-June Medium	30 16000	Rocky-gravelly	July 1960 100 tons (S49)	Wash-in	$ 450	About 200 AF saved in 1960; greater winter flows have been maintained at lower end: no follow-up
Pioneer Ditch SW of Nathrop	10 cfs Fast	4 4000	Rocky	May 1960 42 tons (S49)	Comb. wash-in multiple-dam	$ 380	Water saved in 1960 produced hay worth $1600; 1961-50% of original seal; 1962-25% of original seal
Missouri Park Ditch NW of Salida	70 cfs Medium	10 37000	Rocky-gravelly	1959-1961 234 tons (S49)	Multiple-dam	$1700	Reduced seep at least 75% (before loss = 8-10 cfs) 90 % of original seal estimated during 1962
North Fork Ditch W of Salida	22 cfs Medium	10 5300	Gravel with sand and silt	April 1961 30 tons (S49)	Multiple-dam	$ 180	Water saved in 1961 produced hay worth $1000 ; seal holding well (1962)
Boone No-2 Ditch NW of Salida	6 cfs Medium	4 21000	Loose rock and shale	1948-1961 25 tons (S49)	Wash-in	$ 100	Before: 4cfs loss in 1/4 mile (measured) After: 1 cfs loss in 4 miles (measured)
Bradley Ditch NW of Salida	2 cfs Medium	2 300	Rocky and sandy	April 1962 4 tons (S49)	Wash-in	$ 36	Reduced seep areas below canal
Shepherd Pond NW of Salida	1 AF - -	- - - -	Rocky	May 1962 14 tons (S49)	Scattered by hand	$ 126	Pond will now hold water
Sunnyside Ditch NW of Salida	40 cfs Medium	10 3000	Gravel-sandy	April 1960 69 tons (S49)	Multiple-dam	$ 620	Water saved in 1960 produced hay worth $1200; hay-$500-1961: hay-$500-1962
Branch of the Post Ditch NW of Salida	5 cfs Medium	8 1300	Rocky	June 1960 5 tons (S49)	Wash-in	$ 45	Water saved in 1960 produced hay worth $200; seal held up during 1962
Boyle Pond NW of Salida	1/2 AF - -	- - - -	Gravel and sand	1957-1959 1/2 ton (S49)	Membrane	$ 10 (est)	Before : 50% loss overnight After: practically no loss (seal very effective in 1962)
Tenderfoot Stock Pond N of Salida	- - - -	- - - -	Peat	Fall 1959 2 tons (S49)	Membrane	$ 30 (est)	Bentoniting produced enough water for 50 head of cattle; seal still good in 1962
Kochman Pond W of Salida	1 AF - -	- - - -	Rocky-gravelly	1952 1/2 ton (S49)	Membrane	$ 25 (est)	Before : 100% loss overnight After: holds well
Heberer Pond NW of Salida	- - - -	- - - -	Rocky-gravelly	- - 1 ton (S49)	Membrane	$ 15 (est)	Before: 1/2 foot drop overnight After: pond abandoned soon after treatment
Berg Pond SW of Salida	2 AF - -	- - - -	Rocky-sandy & clay loam	August 1962 16 tons (S49)	Spread on bottom	$ 160	Pond has not been filled since treatment
Lewis Pond W of Howard	2-1/2 AF - -	- - - -	Rock-gravel	June 1962 70 tons (S34)	Spread with tractor-2" mat	$ 500	Reduced losses in new pond
Haggert Ditch S of Howard	2 cfs Medium	3 1000	Rocky-gravelly	June 1962 8 tons (S49)	Wash-in	$ 36	Reduced visible seepage area considerably
Adamson Pond SE of Howard	5 AF - -	- - - -	Cobbles-gravel	April 1960 80 tons (S34)	Membrane	$ 450 (est)	Before: new pond After: 1 foot drop in 24 hours
Goodwin Pond SE of Howard	8 AF - -	- - - -	Rocky-gravelly	April 1960 160 tons (S34)	Membrane	$ 700 (est)	Before: 1-1/2 foot drop in 24 hours After: 1-1/2 foot drop in 1 month
Denek Pond SE of Howard	2 AF - -	- - - -	Rocky-sandy loam	May 1962 24 tons (S49)	Spread on sides & bottom / cat	$ 168	Dried up seep area below pond; saved water valued at about $50 - - for irrigation use
Denek Drainage Ditch SE of Howard	2 cfs Medium	3 200	Rocky-sandy loam	May 1962 3 tons (S49)	Wash-in	$ 20	Dried up seep area below ditch
McCrory Skating Pond N of Cotopaxi	75' x 100' - -	- - - -	Gravelly-sandy	August 1962 12 tons (S49)	Spread on bottom by hand	$ 80	Holding well
Koch Ditch NW of Westcliffe	2 cfs Medium	2 200	Rocky-sandy	1962 1/2 ton (S49)	Wash-in	$ 10	Reduced seep area below ditch
Kettle Ditch S of Westcliffe	3 cfs Medium	3 5000	Rocky	May 1962 15 tons (S49)	Wash-in	$ 150	Good results
Hogback Ditch NW of Westcliffe	5 cfs Fast	4 16000	Rocky	Fall 1960 100 tons (S49)	Wash-in	$1000	Water saved in 1960 produced hay worth $1000; 1961-$2000-hay; 1962-$2000-hay; spring 1962-12 tons (S49)
Peggram Pond SE of Westcliffe	2 AF - -	- - - -	Sandy loam	June 1962 12 tons (S49)	Spread 1/2 inch thick / dozer	$ 132	No benefit--due to not using enough bentonite ; added 18-tons (S49), May 1963
Peggram Ditch SE of Westcliffe	1-1/2 cfs Medium	2 1600	Rocky and Sandy loam	June-July 1962 6 tons (S49)	Multiple-dams every 15 feet	$ 60	Before: 100% loss by end of ditch; after: 20% loss by end of ditch; $200-hay due to water saved (1962)
Berry Pond NW of Westcliffe	1 AF - -	- - - -	Rocky	July 1962 10 tons (S49)	Washed in by supply flow	$ 80	70% reduction in seepage loss; extra water value $100 per year-hay
Coffin Ditch NW of Westcliffe	3 cfs Fast	2 3000	Rocky	- - 1 ton (S49)	Wash-in near upper end	$ 25	$50 benefit each year in hay production

WP* = Wetted perimeter, L = Length of treated section; ** Unless otherwise indicated, information on benefits was supplied by owner or manager

TABLE I

Sheet 2 of 4

FIELD INSTALLATION DATA

Job Title Location	Capacity Grade	WP L	Bed Material	Installation Date Amount of Bentonite	Method of Application	Cost	Benefits and Follow-Up Treatment
ARKANSAS RIVER BASIN (continued)							
Ula Ditch W of Westcliffe	15 cfs Fast	10 8000	Rock-cobble	October 1962 102 tons (S49)	Wash-in from head-end	$1100	Before: 15 cfs at upper end / 6 cfs at lower end After: 3/4 cfs at upper end / 1/4 cfs at lower end
Riss Pond No-1 W of Cripple Creek	1 AF - -	- - - -	Decomposed granite	May 1962 19 tons (S49)	Either blown onto water surface or spread on bottom and banks by hand.	$ 270	Newly constructed ponds with generally 100% loss within 2 days. After treatment there were no visible seep areas below ponds and very little shrink in storage volume. Blow-in method appears quite satisfactory for spreading material in either dry or wet ponds.
Riss Pond No-2 W of Cripple Creek	1 AF - -	- - - -	Decomposed granite	May 1962 45 tons (S49)		$ 630	
Riss Pond No-3 W of Cripple Creek	1 AF - -	- - - -	Decomposed granite	May 1962 14 tons (S49)		$ 200	
Kenon Pond Westcliffe	- - - -	- - - -	- - - -	- - 17 tons (S49)	- - - -	- -	New pond; holding well
Nelson Culifer Ditch N of Canon City	2 cfs Medium	3 3000	Rocky-sandy	1960 16 tons (S28)	Multiple-dam	$ 100 (est)	Before : 50% loss (est) After : 10% loss (est)
Grandview Irrigation Ditch E of Canon City	16 cfs Medium	12 16000	Fractured shale	April 1961 50 tons (S28)	Comb. membrane & multiple-dam	$ 500 (est)	Good seal in bottom but upper banks of canal poorly sealed.
Hydraulic Ditch E of Canon City	40 cfs Medium	12 2000	Fractured shale	April 1962 40 tons (S28)	- -	$ 240 (est)	40 ton-April 1963
Garden Park Ditch N of Canon City	9 cfs Fast	4 4000	Rocky-sandy	May 1960 32 tons (S28)	Wash-in	$ 160 (est)	Before: 30% loss (est) After: 10 % loss (est)
Red Rock Ranch Ponds W of Monument	3-10 AF 4 ponds	- - - -	Gravel-sandy	1959-1960 10 tons (S49)	Membrane	$ 600	Before: would not hold water After: holds very well
Meserow Pond No-1 Near Colorado Springs	1/10 AF - -	- - - -	- - - -	Spring 1960 7 tons (S49)	Membrane	$ 90	Before: 1 foot drop of water level per day After: 1/2 inch drop of water level per day
Meserow Pond No-2 Near Colorado Springs	1/10 Af - -	- - - -	- - - -	Fall 1960 4 tons (S49)	Membrane	$ 60	Before: 1 foot drop of water level per day After: 1/2 inch drop of water level per day
Fountain Mutual Ditch SE of Colorado Springs	8 cfs Medium	4 1500	Sandy loam	July 60-May 61 75 tons (S28)	Wash-in	$ 750	Approximately 60 AF of water saved in 1961 worth about $360; seal holding well (1962); 20 tons (S 28) 1962
Security Village Lagoons SW of Security Village	2 (acres) - -	- - - -	Sand & gravel	Summer 1959 600 tons (S28)	Membrane	$6000	Was lined during construction--holding well in 1962
Ft. Lyon Canal NE of McClave	250 cfs Medium	30 2300	Fractured limestone	September 1962 199 tons (S44-3)	Multiple-dam	$2027	Unsatisfactory installation--no long term effects noticed
RIO GRANDE BASIN							
Cross Creek Pond NW of Saguache	30' x 50' - -	- - - -	Rocky	June 1962 4-1/2 tons (S-49)	Spread by hand & compacted/cat	$ 95	Before: 100% loss within a short time After: 50% loss;holding good-1963
Mill Creek Pond W of Saguache	30' x 50' - -	- - - -	Rocky	June 1962 4-1/2 tons (S-49)	Spread by hand & compacted/cat	$ 95	New pond holding good-1963
Alder Silver Pond N of Saguache	30' x 50' - -	- - - -	Rocky	June 1962 4-1/2 tons (S-49)	Spread by hand & compacted/cat	$ 95	Small seep area still exists - 1963; holding good - 1963
House Log Pond W of Saguache	30' x 50' - -	- - - -	Rocky	June 1962 4-1/2 tons (S-49)	Spread by hand and disced	$ 95	Holding good-1963
Shewalter Pond S of Poncha Pass	6-1/2 AF - -	- - - -	Gravel-shale, peat	1959-1960 123 tons (S49)	Membrane	$1100	Before: 50% loss per day After: Majority of seep stopped (follow-up treatment planned in 1962)
Dominick Ranch (creek) E of Villa Grove	- - Fast	- - 5000	Rocky	1960 8 tons (S49)	Wash-in	$ 90 (est)	Water saved in 1960 produced hay worth $1500; 16 tons added-1963; holding good
Steele Creek SE of Villa Grove	- - Fast	- - 8000	Rocky	June 1960 20 tons (S49)	Wash-in	$ 250 (est)	Water saved in 1960 produced hay worth $1500; available water in 1962 irrigation season due to bentoniting
Cotton Creek Ditch SE of Villa Grove	15 cfs Fast	8 17500	Cobbles-gravel	July 1961 210 tons (S49)	Wash-in	$3000 (est)	Saved about 1000 AF during 1961 irrigation season; not used in 1962
O'Brien Ditch SE of Villa Grove	10 cfs Variable	6 19000	Gravel-sand	November 1959 136 tons (S49)	Multiple-dam	$1670	Before: 4 cfs loss in 1/4 mile After: 3 cfs loss in 3-1/2 miles; holding good-1963
Shellabarger Ditch SE of Villa Grove	10 cfs Fast	6 11000	Gravel-sand	1959-1960 50 tons (S49)	Multiple-dam	$ 600	Before: 3 cfs loss in 2 miles After: 1 cfs loss in 2 miles
Newhall Pond Near Crestone	Stock tank bottom	- - - -	Gravel-sand	May 1962 1/2 ton (S49)	Scattered by hand 1" thick	$ 10	Good results--tank holds water
Garner Pond W of Moffat	100' x 100' - -	- - - -	Gravel-sand	May 1962 22 tons (S49)	Scattered and disced	$ 140	Results were satisfactory--follow-up treatrent planned
Brace Pond No-1 and No-2 N of Center	10 & 12 AF - -	- - - -	Gravel-sand	Jan. 1956; Jan 1960 1500 tons (local)	Membrane	$3000	Total benefits of Ponds = $1500 per year;seal holding well (1962) ; holding good-1963
Coors No-3 Ditch N oc Center	6 cfs Slow	7 1320	Gravel-sand	August 1959 12 tons (S49)	Multiple-dam with ditcher	$ 200	Dried up seep area beside ditch; no visible seepage (1962)
Hooper School Pond SE of Hooper	1/3 AF - -	- - - -	Sandy loam	1959-1960 30 tons (S49)	Membrane	$ 250 (est)	Before: 100% loss in 10 hours After: practically no loss (fair seal still existing (1962)
Schooler Pond SE of Hooper	1 (acre) - -	- - - -	Sandy	Fall 1960 210 tons (S-40)	Membrane- no compaction	$ 250	Holds water-did not before
Mosca School Pond W of Mosca	1/2 AF - -	- - - -	Sandy loam	Oct. 59 & Sept. 60 70 tons (S49 + loc.)	Membrane	$ 300 (est)	Recreational value = $250 per year;holding very well 1962
Alamosa Lagoon Near Alamosa	15 (acres) - -	- - - -	Gravel-sand, clay topsoil	- - 148 tons (S49)	Spread with harrow & disced	$3000	72 ton (S49) added Nov. 1962, no seepage evident
Munday Pond SW of Alamosa	- - - -	- - - -	Sand-gravel	Fall 1961 62 tons (S49)	Mixed and packed	$ 900	Holding good-1963
Wright Ditch E of Monte Vista	2 cfs Slow	6 800	Blow-sand	Spring 1962 3.3 tons (S49)	Mixed into bed material	- -	Bentonite mixed into sand to produce a stable ditch
Davie Pond W of Del Norte	1/4 (acre) - -	- - - -	Soil over gravel/roots	Spring 1961 5-1/2 tons (S49)	Washed-in	$ 100	Before: 6 inches per day of water surface drop After: holding well

TABLE I

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FIELD INSTALLATION DATA

Job Title Location	Capacity Grade	WP L	Bed Material	Installation Date Amount of Bentonite	Method of Application	Cost	Benefits and Follow-Up Treatment
RIO GRANDE BASIN (continued)							
Benson Ditch NE of Del Norte	3 cfs Medium	4 1500	Rocky	August 1960 13 tons (S49)	Multiple-dam	$ 200	Bentoniting saves about 90 AF per year; worth about $300 per year as irrigation water
South Fork Highline Ditch W of Del Norte	8 cfs Medium	10 600	Rocky	May 1961 4 tons (S49)	Multiple-dam	$ 70	Value of water saved = $500 per year; 8 tons (S49) added-1962
Davies Ditch W of Del Norte	5 cfs Medium	8 1300	Rocky-gravelly	November 1962 30 tons (S-40)	Multiple-dam	$ 300	Dried up all noticeable seep areas--can now deliver flow to end of ditch where could not before
Quinlan Pond Antonito	- - - -	- - - -	Silty-clay	August 1961 6 tons (S49)	Membrane	$ 40	Water saved due to bentoniting = $100 per year
Trinchera Ranch Ditch SE of Fort Garland	9 cfs 5000	6 5300	Gravel-sand	July 1956 8 tons (S49)	Multiple-dam	$ 100 (est)	Before: 1/2 cfs loss in 1-mile After: 1/5 cfs loss in 1-mile
DOLORES and SAN JUAN RIVER BASINS							
Nanniga Stock Pond Pagosa Springs	1/10 AF - -	- - - -	Gravel with some clay	August 1960 5 tons (S49)	Membrane	$ 125	Before: would not hold water After:
Smith Pond Pagosa Springs	1/2 AF - -	- - - -	Decomposed shale	Spring 1960 3 tons (S49)	Membrane	$ 100	Partial seal only
Lynn Stock Pond Pagosa Springs	1 AF - -	- - - -	Rock-gravel with some clay	July 1960 10 tons (S49)	Membrane	$ 200	Value of water saved = $500 per year
Olson Stock Pond W of Pagosa Springs	1/2 AF - -	- - - -	Soil and shale	July 1960 1 ton (S49)	Membrane	$ 25	Bentoniting produced enough water for 20 head of cattle
Florida Canal E of Durango	124 cfs Medium	23 37000	"Mancos" shale	Summer 1961 30 tons (S49)	Wash-in	$ 700	Estimated increase of 2 cfs -- treated with Wyoming bent. in 1962 with excellent results
Hayden Pond N of Pagosa Springs	1-1/2 AF - -	- - - -	Soil and shale	Spring 1960 1 ton (S49)	Membrane & wash-in	$ 30	Value of water saved = $100 per year
COLORADO RIVER BASIN							
Sloss Ranch Ditch E of Gunnison	10 cfs Medium	4 450	Fractured rock	Fall 1960 10 tons (S49)	Multiple-dam	$ 170 (est)	Seep areas 80% dried up
Chittington Highline Ditch NE of Parlin	32 cfs Medium	9 3000	Rocky-sandy	October 1959 37 tons (S49)	Multiple-dam	$ 650 (est)	Dried up seep areas in meadow below ditch; additional water produced $300 per year - hay
Torney Highline Ditch E of Parlin	20 cfs Medium	10 5300	Rocky-sandy	May 1959 22 tons (S49)	Multiple-dam	$ 480	No noticeable sealing effects-- main problem-- erosion of banks and bottom after sealing
Dunbar Ranch Ditch NE of Almont	5 cfs Medium	2 4000	Open fractured rock and silt	May 1961 7 tons (S49)	Multiple-dam	$ 150	Seal held up for approximately 3 weeks then original seepage rate resumed
Twin Lakes West Slope Ditch SE of Aspen	20-350 cfs Medium	10-28 20000	Fractured rock and talus	1956 & 1957 300 tons (S49) & 500 tons(Wyo)	Multiple-dam	$20,000	Before loss: 100% at low flows After loss: 25% of low flows
Climax Canal No-1 NE of Climax	100 Medium	9 5700	Rocky	1960 91 tons (S49)	Multiple-dam	$1140	Noticeable water saving, but no measurements made ; Added 13 tons-summer 1963
East Mesa Ditch S of Carbondale	30 cfs Medium	15 500	Gravel and sand	April 1960 60 tons (S42)	Membrane	$ 800 (est)	Extensive seep areas dried up
- - - Ditch E of Crested Butte	26 cfs Fast	10 800	Rocky	October 1961 7 tons (S49)	Multiple-dam	$ 68	Before: 30% loss After: satisfactory results
Phillips Reservoir S of Montrose	1/4 acre	- - - -	- -	July 1962 8 tons (S49)	Scattered on bed and banks		
Sandburg Pond Montrose	105'x 105' - -	- - - -	Silty sand	April 1962 12 tons (S49)	Scattered on water surface	$ 150 (est)	Some reduction in seepage loss, but not as much as expected. 2-lbs/ft^2- not sufficient amount
Voss Tank Bottom Montrose	20' diameter - -	- - - -	Sandy - -	- -	Membrane	- -	Seal held well until tank bottom was exposed to to freezing and thawing
Raish Pond Montrose	50' x 50' - -	- - - -	Rocky	May 1962 3 tons (S49)	Surface membrane	$ 50	Will hold 3 to 5 feet of water where before treatment it would not hold water
Farmers Irr. Co. Sub Lat. N of Silt	5 cfs Medium	6 300	Gravel	Summer 1950 4 tons (S42)	Membrane	$ 50 (est.)	No visible seep since treatment
Bookcliff Country Club Pond Near Grand Junction	- -	- - - -	"Mancos" shale	Spring 1957 400 tons (S42)	Membrane	$1200 (est)	Holding well in 1961; still holding in 1963
No. 2 Canal-Orchard Mesa NE of Grand Junction	60 cfs Medium	10 450	Gravel and Shale	July 1960 60 tons (S42)	Wash-in	$ 180 (est.)	Dried up seep area below ditch
Highline Canal NE of Cameo	- - - -	20 1500	Rock with Silty Sand		Membrane		One bank lined -- reduced seepage damage below canal
1st Lift Ditch W of Grand Junction	35 cfs Medium	25 550	Fracture Shale and Silt	Dec. 1960 110 tons (S42)	Membrane	$ 830	Dried up seep area
2nd Lift Ditch W of Grand Junction	13 cfs slow	11 2600	Sandy silt	May 1960 40 tons (S42)	Membrane	$ 400 (est.)	Good initial seal, but did not last -- erosion and crawfish destroyed seal
Redlands Pond Grand Junction	3 AF - -	- - - -			24" wide core placed @ ℄ of dam		Excellent seal achieved; plan to increase capacity of reservoir in near future
Rump Ranch Ditch Grand Junction	4 cfs slow	4 400	Sandy silt	June 1960 10 tons (S42)	Membrane	$ 100 (est.)	Holding well; ditch concreted in 1962
Marshall Nay Ditch. SW of Toponas	4 cfs	4 600	Sandy	June 1961 1/2 ton (S42)	Multiple-dam	$ 20 (est.)	Initial seal good
Hanks Valley Pool Reservoir Montrose	1 AF		Rocky - Gravelly	Fall 1960 3 tons (S49)	Membrane	$ 100 (est.)	Before: would not hold water After: holds very well

TABLE I

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FIELD INSTALLATION DATA

Job Title Location	Capacity Grade	WP L	Bed Material	Installation Date Amount of Bentonite	Method of Application	Cost	Benefits and Follow-Up Treatment
SOUTH PLATE RIVER BASIN							
Circle Farm Pond E of Ft. Collins	8 AF - -	- - - -	Gravel-Sand with some Clay	Oct. 1960 120 tons (S33)	Membrane	$ 600	Before: 3-foot drop in water surface in 3 days After: Considerable seepage still occurring
MacIntyre Ditch E of Berthoud	8 cfs Variable	5 10000	Sandy - Silty	June 1961 90 tons (S37)	Wash-in	$ 300	Dried up seep area along ditch
Boulder Creek Supply Canal SE of Lyons	150 cfs Medium	24	Gravel, Shale, and Limestone	Aug. 1961 200 tons (S37)	Wash-in	$ 500	Partially effective in reducing small seep flows below canal
Duck Lake Dam Repair S of Georgetown			Fractured Rock and Gravel	Aug-Sept. 1961 9 tons (S49)	Membrane	$ 135	Outlet works rebuilt - bentonite mixed into backfill -- satisfactory results
Wellington Lake Feeder Canal SE of Bailey	40 cfs Medium	13 3000	Decomposed Granite	July 1960 36 tons (S49)	Multiple-dam	$ 750	Estimated $2600 worth of water saved during 1961 (520 acre-feet)
W Burlington Ext Canal NE of Denver	35 cfs Slow	12 50000	Sandy	Sept. 1960 52 tons (S37)	Wash-in	$ 150	Some reduction in seepage estimated
Speer Canal NE of Denver	120 cfs Slow	20 20000	Sandy	July 1962 500 tons (S37)	Multiple-dam		Reduced loss 50% after treatment
Platteville Lateral NE of Denver	25 cfs Slow	12	Sandy	July 1962 36 tons (S37)	Wash-in		Some reduction in seepage
Eitel Pond S of Florissant	170' x 100' - -	- - - -	Gravel, Sand and some Clay	Aug. 1962 22 tons (S49)	Spread and harrowed	$ 270	Good results -- some trouble with muskrats

FIELD INSTALLATION DATA

(WYOMING BENTONITE)

Job Title Location	Capacity Grade	WP L	Bed Material	Installation Date Amount of Bentonite	Method of Application	Cost	Benefits and Follow-Up Treatment
RIO GRANDE BASIN							
Coors Farm No-4 Ditch N of Center	6 cfs Slow	2600	Gravel - Sand	May 1956 6 tons (Wyo.)	Jet-Mixer and Ponding	$ 200	Seepage losses reduced 70%; estimated value of water saved $560
H-1 Pond S of Fort Garland	4 AF - -	- - - -	Gravel Sandy Loam	April 1961 7 tons (Wyo.)	Membrane	$ 350	Saved $6 per day pumping cost during irrigation season 1961
R-2 Pond S of Fort Garland	5 AF - -	- -	Gravel - Sandy Loam	April 1961 13 tons (Wyo.)	Membrane	$ 650	Saved $6 per day pumping cost during irrigation season 1961
NORTH PLATTE RIVER BASIN							
Lake John Inlet Ditch NW of Walden	30 cfs Medium	20 500	Gravel - Sand	Spring 1959 30 tons (Wyo.)	Membrane		Holding well (1961), seep in meadows below ditch dried up
SOUTH PLATTE RIVER BASIN							
Hohnholtz Ditch W of Ft. Collins	5 cfs Medium	12 200	Gravel - Sand	Summer 1959 7 tons (Wyo.)	Multiple-dam		Holding well (1961)
Weaver Ranch Ditch NW of Ft. Collins	2 cfs Variable	5 1000	Rocky, Sand and Silt	June 1956 2/3 ton (Wyo.)	Jet-Mixer and Ponding	$ 65	Reduced losses 50% (1956); ditch not used in 1961
N Poudre No. 3 Lateral SW of Wellington	6 cfs Medium	8 9000	Sandy Clay	Sept. 1955 4 tons (Wyo.)	Jet-Mixer and Ponding	$ 125	Saved 1/2 AF per day (measured in 1956) No effective seal remaining in 1961
N Poudre No-4 Lateral SW of Wellington	3 cfs Slow	5 5300	Sandy with Clay layers	1954-1955 10 tons (Wyo.)	Jet-Mixer and Ponding	$ 300	Saved 120 AF during 1955 irrigation season (measured); no seal left in 1961
Little Cache Ditch N of Ft. Collins	3 cfs Slow	5 6600	Sand, Silt and Clay	Fall 1954 2 tons (Wyo.)	Jet-Mixer and Ponding	$ 60	Saved 60 AF during 1955 irrigation season; ditch cleaning destroyed seal in 1958
Farmers Irrigation Ditch E of Loveland	30 cfs Slow	20 2600	Silty Clay	May 1956 3-3/4 tons (Wyo.)	Jet-Mixer and Ponding	$ 150	Saved 126 AF in 1956 (measured); seal nearly gone in 1961
Christian Lateral E of Campion	3 cfs Slow	5 2600	Silty Clay	June 1956 2 tons (Wyo.)	Jet-Mixer and Ponding	$ 95	Saved 14 AF in 1956 (measured); seal nearly gone in 1961
Sand Hill Reservoir NW of Ft. Lupton	Dike		Sandy	1957 100 tons (Wyo.)	Membrane	$ 3100	Extensive seep area below dam dried up
Wanamaker Ditch E of Golden	25 cfs Fast	6 700	Cobbles and Gravel	Summer 1960 4 tons (Wyo.)	Membrane	$ 200	Reduced seepage loss appreciably (1960)
Zimbleman Farm Ditch SW of Keenesburg	3 cfs Fast	4 2600	Sandy	July 1956 1-1/2 tons (Wyo.)	Jet-Mixer and Ponding	$ 95	21 AF saved during 1956 (measured); seal lost during flash-flood wash-out
Bijou Land Co. Ditch W of Ft. Morgan	5 cfs Fast	4 2100	Sandy	April 1956 2 tons (Wyo.)	Jet-Mixer and Ponding	$ 125	Seal did not last due to erosion
Miller Farm Ditch NW of Atwood	2 cfs Slow	5 1000	Sandy	Summer 1956 3 tons (Wyo.)	Jet-Mixer and Ponding	$ 185	42 AF saved during 1956 (measured)

EVALUATION OF CLAYS

During this study, 321 samples of clay from 108 potential deposits in Colorado were tested. The locations of deposits are shown on figure 1 at the front of this report. The sampling is subdivided below:

River basin	No. of samples	Approx. no. of deposits
North Platte	8	2
South Platte	110	38
Arkansas	105	27
Rio Grande	32	11
San Juan	7	3
Colorado	37	16
Yampa-White	22	11
	321	108

Previous Sampling

Virtually all previous sampling and published information of Colorado clays relates to ceramic uses (bricks, tiles, etc.) (18, 19) or to other industrial uses (bleaching, etc.) (20). Sealing uses are largely ignored. Ceramic clays generally are of a nature unsuitable for sealing purposes. Usually they are not sufficiently impermeable. Bleaching clays, however, are usable in some cases, but results of previous evaluations of Colorado clays were of little value in the present study except for locating potential deposits of sealing clay.

Definitions

Clay -- This term is used commonly as both a rock term and a particle size term.

As a rock term, it is applied to a wide variety of materials. Grim (21), for example, defines "clay material" as any fine-grained, natural, earthy, argillaceous material including clays, shales, and argillites of geologists, and soil as defined by engineers, geologists, and agronomists, if such materials are clayey. Many definitions state clay is plastic when wet. Though this is true of most clays, some clays are not plastic when wet--for example, halloysite and flint clay (22).

As a particle size term, clay denotes the materials finer than some given size. This maximum size of particles in the clay category differs between classifications as follows:

System	Maximum size in clay
U. S. Bureau of Soils	5 microns*
M. I. T. (soil mechanics)	2 microns
Wentworth scale (geology)	3.9 microns

* 1 inch = 23,400 microns

The common limit used by engineers and mineralogists is 2 microns. Some definitions also state that 2 microns is the maximum size of particles classified as "colloidal." Colloidal, when applied to clays, usually means very fine-grained--little or no grittiness when tasted.

In contrast to the classification of clay on a particle size basis alone, the "Unified Soil Classification" of the Bureau of Reclamation and the Corps of Engineers divides earth materials into gravel, sand, and silt-clay on a size basis or by sieving. But the division of silt from clay is made on the basis of liquid limit (related to plasticity) with a liquid limit value greater than 50 classified as clay and a liquid value less than 50 classified as silt (performed on material passing No. 40 sieve).

In this report, clay is not defined in one specific way. The clays are described and evaluated in several ways: by particle size distribution (grit content and colloidal yield), chemical characteristics (cation exchange capacity, etc.), sealing properties (filter and layer permeability), and several miscellaneous properties (free swell and mixing indexes).

Clay Minerals -- The clay minerals or the layer silicates as they are commonly called, are composed of varying combinations of silicon-oxygen layers and aluminum-oxygen layers. Metal ions, such as magnesium and iron, may proxy for aluminum and aluminum may proxy for silicon in the sheet structure. The alkalies, such as sodium and potassium, and the alkaline earths, such as calcium and magnesium, are also essential constituents (or adsorbed ions) in most of the clay minerals[6].

The common clay minerals are montmorillonite, illite, and kaolinite. Pure clay minerals, however, are rare, while mixtures of several clay minerals are common. Most clays also contain nonclay contaminants such as quartz, calcite, fieldspar, organic material, and water soluble salts. The clay fraction, however, usually is the dominant influence in regard to physical properties of clay mixtures, such as the sealing potential.

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[6] *For a complete discussion of clay minerals, their structure, composition, and properties, see references (21, 23, 24). For applied uses of the various clay minerals, the 1962 textbook by Grim (21) is especially recommended.*

Montmorillonite is the major clay mineral in most Colorado clays that are favorable clays for sealing purposes. Most of the Colorado clays may also be called bentonite.

Bentonite -- Like clay, bentonite has many meanings. According to Bechtner (25), bentonite was first applied to a peculiar clay occurring in Wyoming and South Dakota distinguished from other clays by its soapy feel when wet and the property of swelling when placed in water. Studies during the past 30 years show that bentonite is composed mainly of the clay mineral, montmorillonite.

According to common definition, bentonite is a fine-grained clay containing 85 percent or more montmorillonite (26). Ross and Shannon (1926) proposed the term bentonite be confined to those clays produced by the alteration of volcanic ash in situ (in-place), and this definition is preferred by Grim (21).

In commercial usage, the term bentonite tends to be restricted to the highly colloidal varieties of the Wyoming high-swelling type. In recent years, however, the term Wyoming-type bentonite has become the common term used when referring to a highly colloidal, high-swelling bentonite. The terms southern-type bentonite and sub-bentonite have been applied to montmorillonite materials that have relatively lower swelling properties than the Wyoming material. Also, in some commercial usage it has been customary to apply the adjective "bentonitic" to clay materials with relatively high colloidal properties without any consideration as to the origin or composition of the material. In some instances, "bentonitic" has been applied where it was thought that the alteration of ash played a role in the origin of an argillaceous material.

For the purposes of this study, the term bentonite is applied to any clay material that exhibits swelling properties (50 percent or more) and in which montmorillonite is a major constituent.

Sampling of Clay Deposits

In the early part of this study, CSU project people did most of the sampling, but during the last 2 years almost all of the initial sampling of new deposits was done by others--individual prospectors and SCS and Extension Service personnel. If laboratory testing results from the initial samples were favorable, followup sampling was completed by the CSU project.

In general, sampling of favorable clay deposits was progressively more detailed, in relation to the development work at the deposit. As the better prospects were opened and explored, additional sampling was done. The deposit work was carried on by private developers. The CSU work was confined mainly to laboratory testing of samples furnished by the developers.

Many kinds of deposits were sampled. A few examples of sampled deposits are shown in figures 14 to 21. In general, the Colorado clays with favorable sealing characteristics are bentonites (with montmorillonite as the dominant clay mineral).

As previously mentioned, bentonite is an extremely variable substance. Its variability is related to the differing rates of chemical breakdown and weathering of the parent minerals found in the original rock or ash material. In some deposits, the conversion process is only partially complete, with more resistant minerals, such as quartz, remaining as contaminants in the clay. Generally, however, the decomposition and conversion process is nearly complete in deposits with commercial possibilities, with less than 30 percent of contaminant materials remaining in the clay.

Figure 14.—Silt deposit in John Martin reservoir on the Arkansas River near Las Animas, Colo.

Figure 15.—Alkali lake bed deposits in the San Luis Valley near Moffat, Colo.

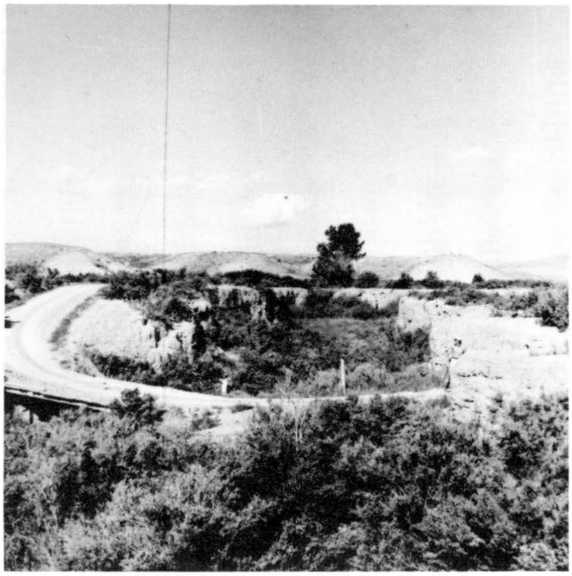


Figure 16.—Flood plain deposit, east of Delta, Colo.

Figure 19.—Clay layers in the Laramie formation, south of Boulder, Colo.

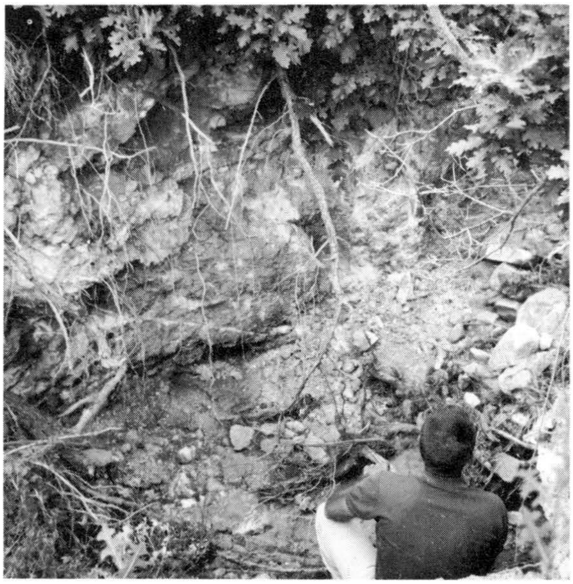


Figure 17.—Bentonite seam in rock near Wetmore, Colo.

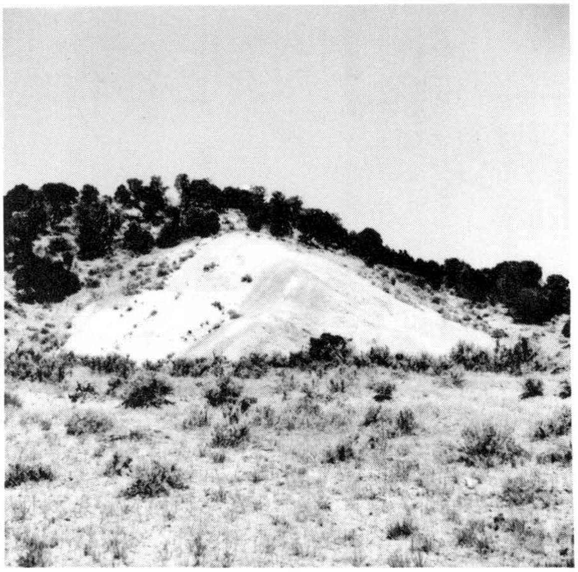


Figure 20.—Badland exposure of clay in the Wasatch formation, north of Meeker, Colo.

Figure 18.—Bentonite layers in the Morrison formation near Fruita, Colo.

Figure 21.—Bentonite seams in volcanic rock exposed in gullies of far slope, east of Conejos, Colo.

Development of Clay Deposits

In contrast to Wyoming bentonites that are available commercially as a processed material of established specification grades, Colorado clays of grades suitable for sealing purposes have been found in this study to be generally undeveloped. A drilling-mud type of Wyoming bentonite is used for seepage control projects. In contrast, production of a uniform quality product is a serious problem with most (but not all) locally available Colorado clays.

During this study it was found that a major part of the development work on Colorado clay deposits has been accomplished by local earth-moving contractors, with lesser amounts done by irrigation districts and individual prospectors.

Since the market for the clay product, as well as most of the deposits, is relatively undeveloped, the major tonnage of clay for sealing purposes has been sold, to date, by those equipped to do both the sealing work and the mining and processing of the clay.

As is to be expected in any new industry, the quality of the produced clay product for canal and pond sealing purposes in Colorado varies widely. One major problem is the understandable tendency of users to buy on a price rather than a quality basis.

Figures 22 and 23 show two developed deposits.

Figure 22.—Bentonite deposit with gravity loading arrangement near Grand Junction, Colo.

Figure 23.—Bentonite pit near Salida, Colo.

Clay Testing Procedure

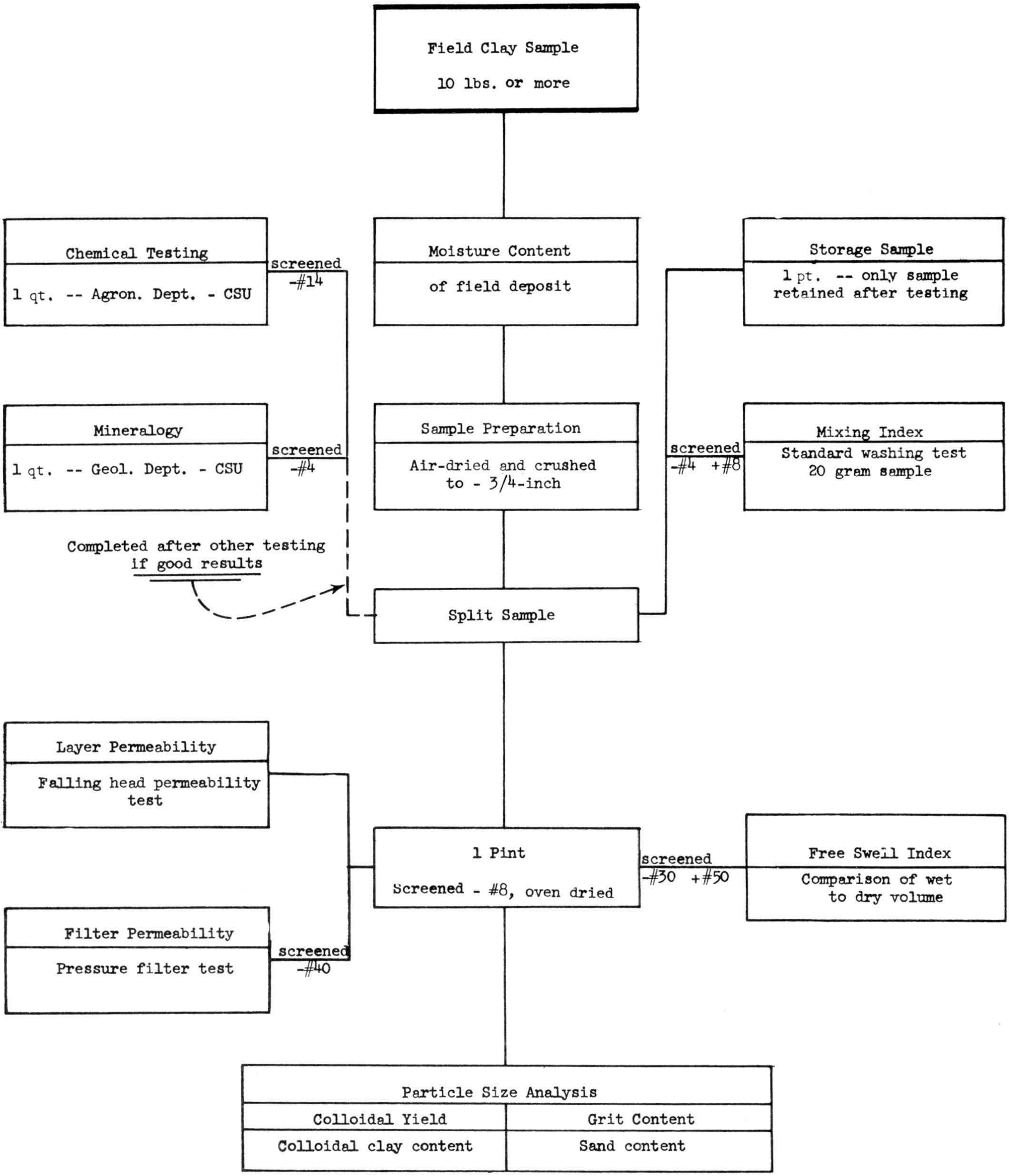
Laboratory tests commonly used to evaluate clays, including bentonites, vary widely with the contemplated use of the clay. Most available tests, such as those used to evaluate clays for use in the ceramic foundry and petroleum industries, do not apply to sealing uses. For example, the tests that define the firing properties of a clay do little toward defining the sealing properties of the clay. However, some of the tests used to evaluate bentonites for drilling purposes have been helpful in the development of test procedures pertinent to canal and pond sealing (27, 28).

Figure 24 is a flow chart of testing procedures used during this work to evaluate the Colorado clays for sealing purposes. Each of the test procedures is discussed briefly in this section. Detailed instructions for each test and the details of development for each test procedure may be assembled in report form at a later date if sufficient interest in such a report develops.

Figures 25 to 32 show the laboratory testing.

Figure 24

Flow Chart for Testing of Clay



Moisture content -- In-place clays at deposits frequently are quite moist--as high as 40 percent for good quality clays. Since gummy wet clay is difficult to use for canal or pond sealing, information on the in-place moisture content is important. Some drying of the clays at the deposits is almost always needed since a dry granular clay is best for sealing purposes.

The determination of moisture content involves weighing a small sample before and after drying, then calculating the moisture content on the basis of the dry weight of clay. Moisture content data were obtained for only a few of the developed deposits of clay, usually on a direct service basis for individual producers and for the specific purpose of encouraging moisture removal (by drying) by the producer.

Sample Preparation -- Briefly, this consists of preparing the field sample, which is often lumpy and even gummy, for laboratory testing. As shown in figure 24, the sample preparation consists of air-drying, crushing to 100 percent passing a 3/4-inch screen, and dividing the sample with a sample splitter into representative portions for the various laboratory test procedures.

Most of the laboratory testing is run on a 1-pint sample of clay, crushed to 100 percent passing a U. S. No. 8 sieve (openings about 0.1 inch) and dried at 105° C for 24 hours. Exceptions include samples used for the mixing index test and for chemical and mineralogical testing. The exceptions are air-dried rather than dried at 105° C. Chemical and mineralogical testing was not run on all samples.

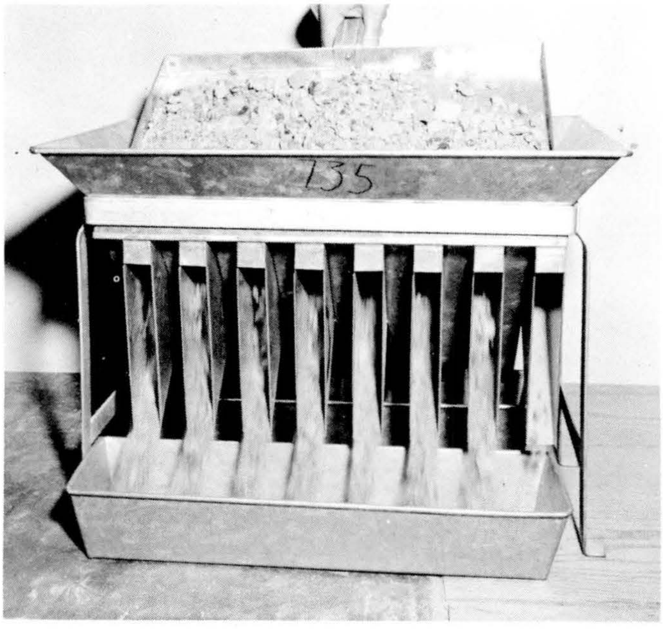


Figure 25.—Splitting sample into representative portions.

Layer Permeability -- This test is pointed at the layer applications--both buried membrane and mixed layer methods. The layer permeability test consists of placing 50 grams of the prepared clay sample in a plastic permeameter (2.5 inches I.D.), tapping the tube gently until the clay layer is uniformly 0.6 inch thick, slowly saturating the clay layer from below (if possible), ponding water above the clay to a depth of 52 inches, initially, and running a falling head permeability test.

Clays acceptable for sealing purposes should have a loss rate of 0.005 ft./day or less in the layer permeability test.

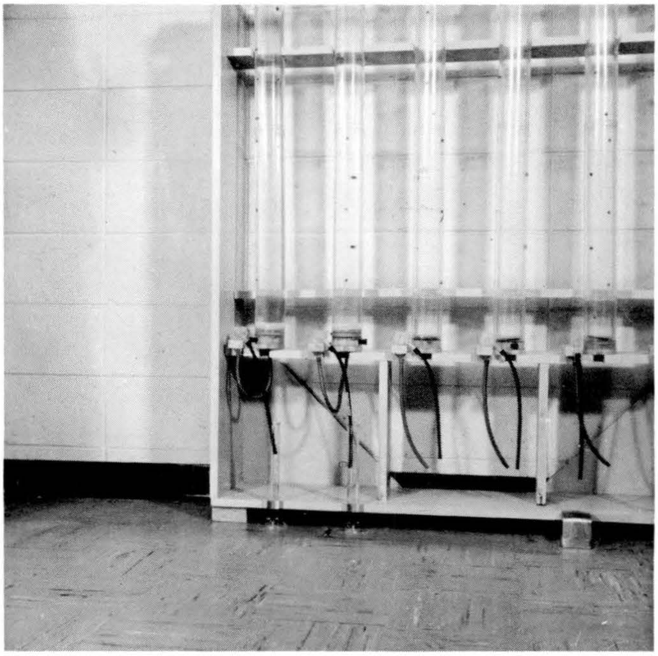


Figure 26.—Equipment for layer permeability test.

Filter Permeability -- This test relates to the wash-in applications where flowing water is used to carry the clay into the leaky zones of the canal or pond. It consists of thoroughly dispersing 8 grams of prepared clay sample into 400 ml. of water, placing this 2 percent mixture in the filter press assembly, applying air pressure equal to 30 inches of mercury (approx. 14.7 psi), and calculating the filter permeability (volume of filtrate divided by the time or ml./min.). The results give a rough measure of the water tightness when the clay is washed into place in the leaky zones of the canal or pond.

A filter permeability loss rate of 10 ml./min. (about 0.61 cu. in./min.) or less is desirable for sealing clays.

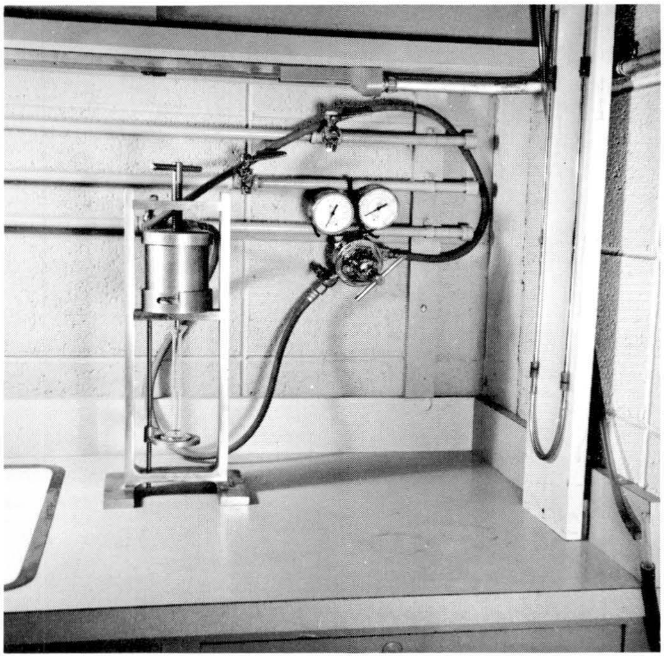


Figure 27.—Filter permeability equipment.

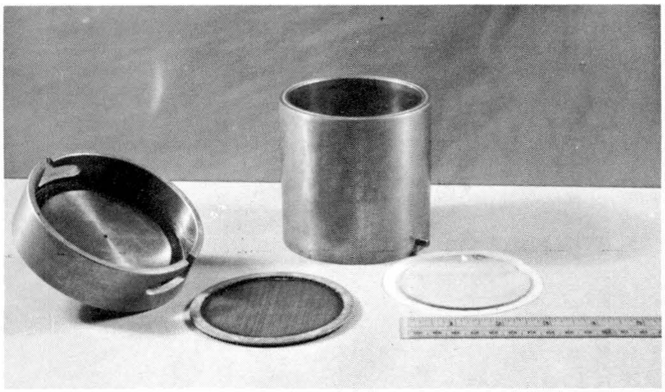


Figure 28.—Filter cup with filter paper insert.

<u>Mixing Index</u> -- This test relates mainly to wash-in applications. It gives a measure of the ease of mixing which is especially important if the clay is to be washed into suspension from dams in a canal. The test is run on a 20-gram sample of air-dried clay that is 100 percent retained on a U.S. No. 8 sieve and 100 percent passing a U.S. No. 4 sieve. The sample is placed in the mixing index apparatus, and washed for 30 seconds with an upward stream of water (under 3 inches of mercury pressure). The mixing index is calculated by determining the percentage of sample lost by washing in this test.

The pressure head (3 inches of mercury or about 3.4 feet of water) and the washing time of 30 seconds was set so that clays with the fastest mixing time in field trials have a mixing index near 100 percent (loss) while the slowest mixing clays have a mixing index near 10 percent (90 percent left after test).

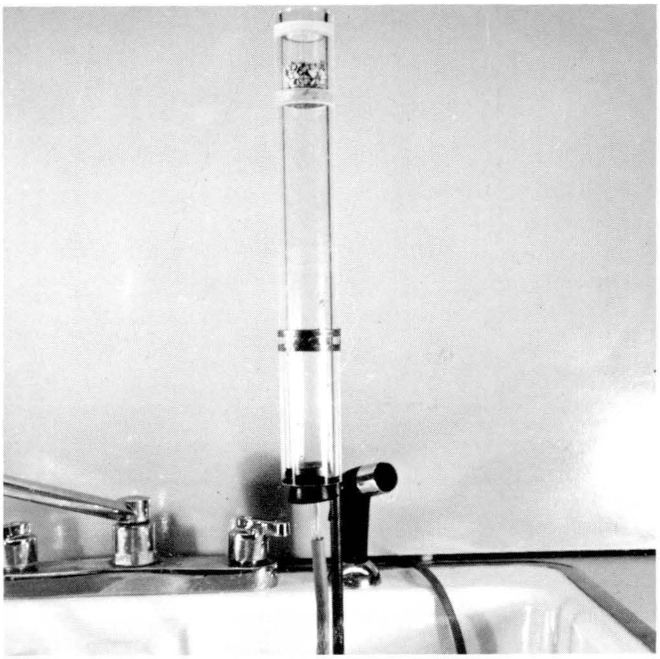


Figure 29.—Mixing index test just prior to start of water washing.

<u>Free Swell Index</u> -- The amount and kind of swelling for a given clay will vary with the technique used for the determination of swelling. The free swell test used in this work is a modification of a procedure used by the Bureau of Reclamation (Petrographic Laboratory Reference No. 60-6). In the test, 10 cc of an oven-dried and screened material (passing U.S. No. 30 screen and retained on U.S. No. 50 screen) is slowly sifted into distilled water in a graduated cylinder. The free swell is the ratio (expressed as percentage) of the wet to dry volume.

Free swell indexes vary from negative values (shrinks when wetted) to as much as 2,000 percent. The minimum values of swell index vary with the type of sealing clay, but for all types it should exceed 50 percent.

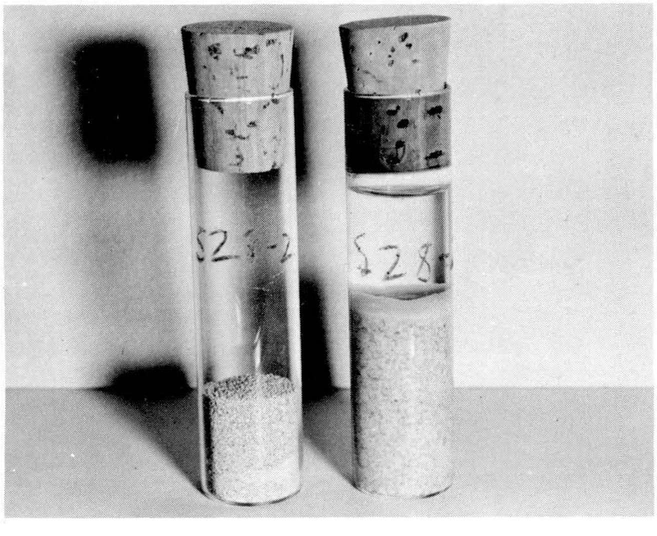


Figure 30.—Free swell test.

Particle Size Analysis -- Because of the large number of samples processed during this work, a complete particle size analysis was run on only a few of the clay samples. Two particle size determinations were made on all of the clay samples:

1. Colloidal yield -- This is the percentage (by weight) of the clay sample that is extremely fine-grained or of colloidal clay size (minus 2 micron size of little or no grittiness when tasted). It is determined by dispersing or mixing thoroughly 20 grams of clay with 2.0 grams of dispersant (sodium tripolyphosphate) in 1,000 cc (1.08 qts.) of distilled water. After thorough dispersing, the mixture is allowed to set undisturbed for 24 hours. The amount of material remaining in suspension after 24 hours is determined by hydrometer analysis. The colloidal yield is defined in this work as the percentage of the original sample remaining in suspension after 24 hours.

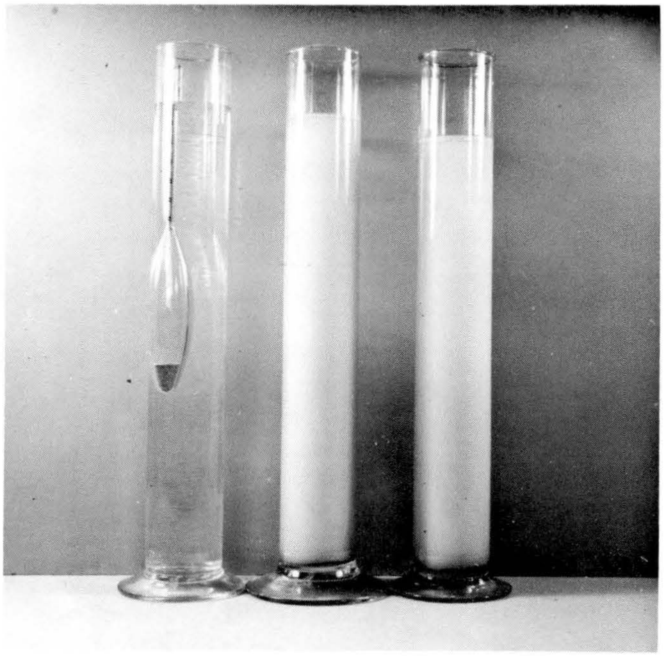


Figure 31.–Colloidal yield test.


Figure 32.–Grit content test.

2. Grit content -- Upon completion of the colloidal yield test, the mixture is washed through a U.S. No. 200 sieve. The grit content is the percentage (by weight) of the total sample that is retained on the No. 200 sieve (openings-- .074 mm or .003 in.). This is the nonsoftening (upon wetting) or sand fraction of the sample.

Chemical and Mineralogical Analyses -- This testing was performed on only the best or the most unusual Colorado clays. Chemical testing was performed by the chemical laboratory of the CSU Agronomy Department. Mineralogical testing was done by the CSU Geology Department. Chemical testing included: cation exchange capacity, water soluble cations, exchangeable cations, exchangeable sodium percentage, saturation percentage, conductivity, $CaCO_3$ equivalent, and pH and gypsum content (29, 30). The mineralogical testing was performed by X-ray diffraction.

Discussion of Clay Testing Results

The results of the testing of clays in this study are shown in table II at the end of this section. The results are discussed by tests.

Layer Permeability -- This test pertains most directly to layer applications. With the permeability rate as determined in this test, a rough idea of the thickness of clay layer required in field installations may be obtained. For example, assuming a goal of reducing the loss to about a 1-inch drop in water level in 24 hours,[7] the tabulation below will apply:

Layer permeability (ft./day)	Thickness of loosely placed clay layer* if water depth is			
	1 ft.	3 ft.	5 ft.	10 ft.
.0100	1.4	4.3	7.2	14.4
.0050	0.7	2.2	3.6	7.2
.0010	0.1	0.4	0.7	1.4
.0001	0.01	0.04	0.07	0.14

*Necessary to reduce seepage loss to 1'' drop/24 hrs.

The layer thickness values are by no means exact. They are helpful in a general way only. For example, most clays when placed in field installations are compacted. The values shown in the table above are for loosely placed clay. Since compacting reduces permeability, the above thicknesses if used in field installations, should be on the safe side. Also, if a prepared field clay has lumps up to 1/4-inch size, it will be impossible to spread clays in layers as thin as 0.01 to 0.1 inches. The minimum thickness of layers for a given clay relates not only to the permeability of clay but also to the maximum size of lump in the clay.

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[7] *This is a reasonable goal, especially since it is about the same size as the maximum evaporation loss from a pond in this area on a hot and windy day.*

Filter Permeability -- This test relates most directly to wash-in applications. To give a general idea of what the results mean, loss rates for several materials are listed below:

One-eighth inch of No. 40 Ottawa sand lost 1,440 ml./min.

One-eighth inch of local sandy soil lost 1,003 ml./min.

Filter paper alone (at bottom of cup) lost 651 ml./min.

Best clays have loss rates below 10 ml./min. (.61 in^3/min.)

The test should give results on the safe side because the pressure head used in this test (equal to about 34 feet of water) exceeds that found in virtually all field installations in ponds or canals.

Mixing Index -- In general, clays with low values of layer and filter permeability also show low values of mixing index. The few exceptions to this generalization--those with high mixing index and low permeability--are best for sealing purposes using the wash-in methods in canals and ponds. The favorable clays for wash-in work have a mixing index of 40 percent or more.

An interesting research problem would be the attempt to learn why only a relatively few of the impermeable clays have a high mixing index. It seems likely that the key to this problem is related to the geological history of the clay deposit. Those deposits which have been deeply buried in the past seem to have low mixing indexes, while the clays of high mixing index are usually in recent deposits with no past history of deep burial.

Free Swell Index -- From the standpoint of sealing properties, the following has been observed:

1. All clays have a high swell index (600 percent or greater) have low permeabilities.

2. All clays with high permeabilities have a low swell index (50 percent or less).

3. Some clays with a low swell index also have low permeabilities.

Thus, if clays are selected on the basis of a high swell index, no poor sealers will be picked, but some good sealing clays (especially those best for wash-in applications) will be missed.

The swelling is especially helpful when the clay is placed dry in a canal or pond. The swelling upon wetting reduces the permeability. In low-swell or nonswelling clays, permeability reduction upon wetting will not occur. Compacting of the clay layer is required to produce low permeabilities in most low to nonswelling clays.

With only a few exceptions, the Colorado clays showed a free swell index below 300 percent.

Particle Size Analyses -- For many sealing applications, a high colloidal yield (50 percent or more) and a low grit content (10 percent or less) is desirable, but for sealing coarse rocky materials up to 30 percent grit (or more in extreme cases) may be necessary as bridging agents in large voids of the leaky materials. Thus, a high colloidal yield and a low grit content are not infallible indications of a good clay for sealing purposes. In fact, in some cases such a clay will not hold water. For example, see the results of testing of sample S 33-1 in table II (sheet 5 of 9).

Chemical and Mineralogical Analyses -- The results of this testing are given in table III at the end of this section. A few generalizations relating to Colorado clays can be made.

In general, the favorable clays for sealing are those with the highest cation exchange capacity, exchangeable sodium percentage, and pH, and the lowest content of gypsum and water soluble cations. Also, the favorable clays generally are dominantly montmorillonite.

Suitable clays usually exhibit some swelling upon wetting and almost always are 10 percent or more sodium-saturated.

A general idea of the chemical and mineralogical qualities of the clay can be obtained from the routine testing. In the filter permeability test, for example, clays that give weak fluffy filter cakes and high filter loss values are usually calcium clays, whereas those that give thin, tough filter cakes and low filter loss values are usually sodium clays.

The free swell index test will also give indications of the clay minerals present. Kaolins, for example, swell only slightly when wetted or hydrated. Sodium montmorillonite, on the other extreme, commonly swells in water to many times its dry volume--sometimes as much as 20 times or more. Calcium or magnesium montmorillonite and hydrous mica, or so-called illite, fall between the two extremes in swelling properties--usually in the range of 1 to 5 times the dry volume (or 100 percent to 500 percent) (29, 30, 31).

Since the Colorado clays are usually mixtures of various clay and nonclay minerals, they give a wide range of colloidal yields and grit contents. For comparison purposes, however, a pure sodium montmorillonite will commonly give a colloidal yield of 80 percent or more (with or without dispersant) and a grit content of 5 percent or less. In contrast, the same montmorillonite when calcium-saturated (in other words, a calcium montmorillonite) may give a colloidal yield as high as 80 percent with dispersant and as low as 40 percent or less without dispersant. The grit content of a sodium clay will usually be about the same as for its calcium counterpart.

TABLE II Sheet 1 of 9 LABORATORY TEST DATA

Lab No.	Name and Location	Year Tested	Colloidal Yield %	Grit Content %	Permeability Tests				Mixing Index %	Swell Index %	Add'l Testing
					Filter (ml/min)		Layer (ft/day)				
					> 10	< 10	> 0.005	< 0.005			
	ARKANSAS RIVER BASIN										
S29-1	Poncha Springs (Mumma) 5 mi W of Salida	60	15.0	19.7	24.8						
S48-1	"	60	30.6	2.4		4.3		0.0003	89.7	110	*
-2	"	60	18.4	21.4		3.0		0.0005	61.5	42	
S49-1	Silver Rocker (Lamberg) 3 mi SW of Howard	60	15.9	37.5		3.4		0.001	73.3	35	
-2	"	60	17.6	57.2		2.7		0.001	21.6	20	
-3	"	60	35.6	6.7		2.5		0.0003	77.7	100	*
-4	"	60	49.8	22.1		1.9		0.0003	54.3	75	
-5	"	61	30.2	15.0		2.9		0.0009	83.3	105	
-6	"	61	34.3	18.8		4.4		0.001	96.5	200	
-7	"	61	26.4	34.5		3.0		0.002	62.4	90	
-8	"	61	21.6	9.2		2.9		0.001	81.3	95	*
-9	"	61	20.4	9.7		2.7		0.001	77.6	110	
-10	"	62	40.0	5.1		2.2		0.001	33.4	280	
S34-1	F. G. Kessler 2 mi S of Howard	60	26.1	0.9	26.7			0.0	93.5	60	*
-2	"	60	22.9	0.8	19.1		0.015			60	
-3	"	60	20.2	28.4	18.6		0.027				
-4	"	60	14.2	51.4	23.1		0.018				
-5	"	60	27.7	2.6	10.1			0.001	97.5	50	
-6	"	60	22.5	1.4	36.2		0.032		93.9	68	*
S47-1	-- 2 mi E of Silver Cliff	60	24.3	12.2	18.0		0.173				*
S78-1	Fred Vahldick 2 mi W of Rosita	60	14.7	28.6	39.0						
-2	"	60	42.2	15.5	36.5		0.067		91.5	25	
-3	"	61	23.3	41.5	11.9						
-4	"	61	41.8	18.8	12.8						
-5	" 3/4 mi S of Schoolfield Rd	61	31.2	48.9	12.3		0.034		62.8	40	
-6	" Waste mat'l at perlite mine	61	56.1	25.7		9.4	0.046		81.8	75	
-7	Kastendieck-near Westcliffe	63	25.0	24.6		7.3	0.13		44.2	35	
-8	"	63	30.0	23.4		7.7	0.24		43.2	50	
S112-1	Silver Cliff Sand	63	15.0	5.1		9.8	0.05				
-2	"	63	10.0	17.9	10.7		0.01			30	
S64-1	Harvey Bros. Ranch Near Parkdale	60	44.3	18.8	130.0		0.074		38.1	40	
-2	" From cut .4 mi N of house	60	28.7	18.0	79.2						
-3	" Aban. clay mine	60	23.9	8.3		8.5		0.003	11.0	-10	
S32-1	Davidson Ranch SW of 11 mile Reservoir	60	33.0	12.1	79.1		0.028		91.2	55	
S28-1	Frank Dilley Ranch 8 mi N of Canon City	60	39.5	8.3		5.1		0.0006	77.5	98	
-2	" 1st nob east	60	39.6	7.9		4.8		0.002	34.9	88	*
-3	" 2nd nob east	60	37.0	9.1		10.3		0.0006	48.5	90	
-4	"	60	49.3	2.0		7.7		0.003		30	

Compiled by G. A. Lutz and L. G. White

* See Table III for results of chemical and mineralogical testing of these samples

TABLE II

Sheet 2 of 9

LABORATORY TEST DATA

Lab No.	Name and Location	Year Tested	Colloidal Yield %	Grit Content %	Permeability Tests: Filter (ml/min) > 10	Permeability Tests: Filter (ml/min) < 10	Permeability Tests: Layer (ft/day) > 0.005	Permeability Tests: Layer (ft/day) < 0.005	Mixing Index %	Swell Index %	Add'l Testing
	ARKANSAS RIVER BASIN (Continued)										
S28-5	Frank Dilley Ranch 8 mi N of Canon City	60	30.2	5.8		8.3	0.007			60	
-6	"	60	43.8	6.0		8.0		0.0		100	
-7	" East side of stock pile	61	34.4	11.4		7.7		0.004	57.9	90	*
-8	" West side of stock pile	61	31.3	11.7		8.9		0.004	63.9	70	
-9	"	61	33.9	8.8		5.5		0.005	51.3	50	
-10	"	61	37.1	9.6		4.7	0.008		85.0	60	
-11	"	61	35.8	8.8		4.0	0.006		98.2	5	
-12	"	61	34.1	8.5		4.7	0.009		96.0	40	
-13	"	61	42.8	5.2		5.7		0.003	93.9	75	
-14	" Nob No. 2	62	33.8	6.3		6.4		0.002	46.7	90	
-15	" Nob No. 3	62	27.5	5.1		5.8		0.004	29.8	65	
S105-1	City Reservoir embankment 3 mi S of Florence	62	20.0	9.2		8.7	0.060		43.3	30	
-2	"	62	11.1	10.1	10.2		0.080		43.0	10	
-3	" 200' N	62	20.0	13.9	11.5		0.070		53.0	20	
-4	" 200' S	62	15.0	11.2	11.1		0.150		53.0	10	
S87-1	Sponholtz (Essmeier) 1.5 mi W of Wetmore	61	31.0	4.8	25.6		0.006		61.3	90	
-2	" 2.5 mi NW of Wetmore	61	28.4	10.1	18.9		0.040		59.9	20	
S82-1	Hoyt Adkins Ranch Near Penrose	61	20.8	42.7		4.1		0.0003	97.3	10	
-2	"	62	15.0	43.6		5.0	0.030		94.0	0	
S59-1	A. L. Wands -- near Pueblo From new pit	60	10.2	67.2	10.4		0.036				
-2	" From old pit	60	25.0	27.0	11.8		0.032				
S73-1	W. A. Mahan -- near Pueblo	60	17.2	65.3		9.8	0.039				
-2	" Lt. grey to green	60	31.7	3.2	17.0		0.034		82.4	50	*
-3	W. H. Everhart Near Pueblo	61	11.1	8.0	11.0		0.049				
S35-1	H. N. Embry Near Pueblo	60	10.0	73.1	75.6		0.069				
S60-1	Nat. Clay Products (Welte) In S Colo. Springs	60	25.0	9.4	48.8		0.057		38.1	20	
-2	" 10' below S60-1	60	30.0	5.0	35.6		0.039		42.6	25	
-3	" Composite of floor mat'l	60	27.5	6.5	38.0		0.033		63.6	50	
-4	" Olive brn shale above S60-1	60	33.2	3.5	57.0		0.030		62.1	30	*
S86-1	Mill tailings (D.Hamon) 3 mi W of Victor	61	32.7	38.5		6.1	0.030		10.5	20	
S46-1	McAlpin Ranch West of Red Wing	60	39.7	25.0		1.6		0.0	12.2	90	
S44-1	Rodgers Lease -- S of Las Animas above Muddy Cr. Res.	60	55.3	5.7		0.9		0.0	12.6	230	
-2	"	60	63.0	4.1		0.9		0.0	11.5	310	
-3	Stough Ranch -- S of Las Animas above Muddy Cr. Res.	60	55.0	7.8		4.7		0.001	31.5	110	
-4	School Section (Butterfield) above Muddy Cr. Res.	60	66.1	1.9		3.6		0.0007	8.5	250	*
-5	"	60	58.0	3.9		1.0		0.0	16.9	150	
-6	"	61	31.0	35.2		19.4	0.220		96.9		
-7	"	61	46.0	13.8		64.7	0.170		23.9		

Compiled by G. A. Lutz and L. G. White

* See Table III for results of chemical and mineralogical testing of these samples

TABLE II

Sheet 3 of 9

LABORATORY TEST DATA

Lab No.	Name and Location	Year Tested	Colloidal Yield %	Grit Content %	Permeability Tests				Mixing Index %	Swell Index %	Add'l Testing
					Filter (ml/min)		Layer (ft/day)				
					> 10	< 10	> 0.005	< 0.005			
	ARKANSAS RIVER BASIN (Continued)										
S44-8	School Section (Butterfield) Above Muddy Cr. Res.	61	38.2	38.1		15.4	0.028		69.3		
-9	"	61	59.5	0.8		1.6		0.001	19.1		
-10	"	61	39.6	6.7		1.9		0.0	19.6		
-11	"	61	30.3	23.9	10.0			0.001	42.6		
-12	"	61	59.9	0.8		1.9		0.0003	41.1		
-13	"	61	40.4	6.8		1.3		0.0	7.1		
-15	"	62	52.9	2.3		1.4		0.0	15.4	325	
-16	" Brown and Reddish mat'l	62	51.0	0.9		5.3		0.0003	21.6	240	
-17	Stough Greenish mat'l	62	60.0	2.1		6.0		0.002	20.3	210	
-18	School Section (Butterfield) Black mat'l	62	80.0	0.8		2.6		0.0003	17.3	640	
-19	" Wet mat'l above Muddy Cr.	62	55.0	2.6		1.0		0.0	13.5	250	
-20	" Dry mat'l above Muddy Cr.	62	51.5	5.6		1.3		0.0	7.4	225	
-21	" Random sample of stockpile	62	53.8	2.5		1.6		0.0002	16.6	185	*
-22	" Wet mat'l in stockpile	62	33.8	0.9		3.1		0.002		80	
-23	" Dry mat'l on surface	62	55.0	4.1		1.9		0.0003		220	
-24	" Upper green	62	60.0	8.4		1.3				175	
-25	" Upper black	62	82.5	0.6		1.2				250	
-26	" 2nd bed -- grey green	62	52.5	16.5		1.6				145	
-27	" 1st bed -- brown	62	46.3	7.6		3.7				165	
-28	" Grey clay	62	53.8	2.6		2.6				310	
-29	" 2nd bed -- black	62	83.8	0.2		0.8				440	
-30	" 3rd bed -- green	62	59.4	1.2		0.9				275	
-31	" S Draw -- 3' green	62	65.0	1.2		1.0					
-32	" Composite sample	62	72.5	3.6		1.5		0.001	15	250	*
S45-1	A. F. Wagner 2 mi SW of Las Animas	60	55.6	7.9	16.8			0.005	38.2	130	*
S44-14	Silt deposited in John Martin Res. near Lamar	61	52.0	0.1	15.9		0.030			75	
S58-1	Robinson Brick & Tile pit 3 mi S of Calhan	60	29.5	25.1	12.5						
-2	"	60	35.8	25.3	12.5						
S57-1	Robinson Brick & Tile pit 2-1/2 mi SW of Peyton	60	10.8	22.3	39.8						
	SOUTH PLATTE RIVER BASIN										
S61-1	- - 3.5 mi E of Castle Rock on Highway 86	60	21.3	30.3	32.2						
S62-1	Stevens Ranch (Wisenhunt) pit near Castle Rock	60	52.4	2.1	11.2			0.004	12.6	40	*
-2	" Yellow from stockpile	60	43.1	5.3		8.9		0.003	10.9	20	*
S63-2	Cline prospects -- near Kiowa -- Tucker lot No. 1	61	56.0	0.9		6.3		0.004	67.4	60	
-3	" -- Tucker lot No. 2	61	55.9	0.2		4.4	0.057		16.3	80	
-4	" -- Cline-Kruse No. 1	61	56.4	0.4		4.9		0.0009	10.2	120	
-5	" -- Tucker lot No. 3	62	46.5	0.4	15.2			0.005	36.3	50	

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TABLE II

Sheet 4 of 9

LABORATORY TEST DATA

Lab No.	Name and Location	Year Tested	Colloidal Yield %	Grit Content %	Permeability Tests				Mixing Index %	Swell Index %	Add'l Testing
					Filter (ml/min)		Layer (ft/ day)				
					> 10	< 10	> 0.005	< 0.005			
SOUTH PLATTE RIVER BASIN (Continued)											
S63-6	Cline prospects -- near Kiowa -- Tucker lot No. 4	62	32.6	0.6		7.5		0.002	13.5	36	
-7	" Tucker lot No. 5	62	36.8	3.9		9.6		0.002	16.9	45	
-8	" 1/2 mi S of Sedmore, lot No. 1	62	25.1	8.5	47.9		0.050		72.0	45	
-9	" Sec. 18 - Pine	62	26.4	3.3	14.4		0.200		97.8	110	
-10	"	62	48.8	6.9		5.0		0.004		60	
S65-1	-- Road cut on Highway 86, 1/4 mi W of Kiowa	61	26.6	18.9	17.6						
S56-1	Lee Cox 1 mi NE of Morrison	60	26.0	5.4	19.4		0.028		13.2	10	*
S66-1	Henry Pallaoro -- on Turkey Creek near 4-corners Uranium	60	23.5	41.7	16.9						
S39-1	Standley Lake Prospect near Arvada	60	30.3	18.8	36.1		0.048		70.4	35	
-2	"	60	40.3	15.5	18.1		0.021		63.1	30	
S50-1	Mine tailings Near Golden	60	11.5	34.6	56.0						
S67-1	G. C. Bennetts -- near Golden from mine in Dakota fm.	60	5.0	82.1	56.4						
-2	" From open pit in Dak. fm.	60	49.5	0.2		6.8		0.003	16.8	40	*
S68-1	G. W. Lindsey -- E. side of Hy 93, 6.5 mi N of Golden	60	33.4	2.8		5.3	0.006		66.7	30	*
S37-1	Rocky Flats -- N of Golden on Hy 93	60	14.7	49.7	25.6		0.07				
-4	"	60	28.6	12.5	20.2		0.014		58.6	25	
-2	Strainland lease -- N of Golden in Rocky Flats area	60	53.8	1.7	15.5		0.011		12.3	30	*
-3	Plainview lease -- N of Golden in Rocky Flats area	60	15.0	5.6	15.9		0.02				
-5	Marshall Lake (Conda) near Marshall, S of Boulder	60	43.8	1.4	23.7			0.003	68.7	50	*
-6	"	61	52.2	0.2	16.0		0.036			30	
-7	"	61	53.2	0.2	16.4		0.034			55	
-8	"	61	40.5	0.1	17.0		0.035			50	
-9	"	61	40.1	0.6	12.7		0.025			40	
-10	"	61	52.5	0.1	15.9		0.032			75	
-11	"	61	47.5	0.4	15.9		0.059		69.9	50	*
-12	" Billington sample	62	55.0	0.2		6.2	0.038		59.0	70	
-13	" NW pile in pit	62	55.0	0.4		5.4	0.016		44.0	70	
-14	" SE pile in pit	62	53.0	0.3		6.5	0.025		54.0	70	
-15	" Auger pile	62	55.0	0.6		6.1	0.018		43.0	70	
-16	" Over-size pile	62	52.5	0.5		6.2	0.013		62.0	70	
-17	" From stockpile of screened	62	51.2	0.6		7.0	0.022		52.6	60	
-18	" From stockpile of over-size	62	50.0	0.7		6.2	0.030		45.5	60	
-19	" Used in Poudre Valley Ditch	63	47.5	0.6		5.3	0.03		56.1	70	
S80-1	" Used in Boulder Supply Canal	61	20.0	20.9	19.3						
S55-1	E Side of Clover Basin Res. SW of Longmont	60	30.0	0.8	36.0		0.023		19.4	46	*
S54-1	Brick plant quarry -- between Fort Collins and Loveland	60	35.0	0.8	26.3		0.030		21.3	30	*
S102-1	Watts near Windsor	61	33.1	2.9	19.4		0.137		68.7	50	
S76-1	Heinemann -- SW of Fort Collins	61	30.3	23.8					26.2		

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TABLE II

Sheet 5 of 9

LABORATORY TEST DATA

Lab No.	Name and Location	Year Tested	Colloidal Yield %	Grit Content %	Permeability Tests: Filter (ml/min) > 10	Permeability Tests: Filter (ml/min) < 10	Permeability Tests: Layer (ft/day) > 0.005	Permeability Tests: Layer (ft/day) < 0.005	Mixing Index %	Swell Index %	Add'l Testing
	SOUTH PLATTE RIVER BASIN (Continued)										
S41-1	Vandleman -- Bingham Hill Road NW of Fort Collins	60	16.0	11.9	22.5		0.03				
S51-1	Leroy Smith near Fort Collins	60	29.5	31.4	29.1						
S41-2	Leroy Smith Pond (black muck) East of Fort Collins	61	10.5	20.2	10.1		0.20				
S83-1	Sherman Roberts near Fort Collins	61	23.5	23.4		5.4		0.001	46.3	35	
-2	"	61	22.7	27.9		3.4		0.0006	69.9	25	
S69-1	Morrison fm -- 3.5 mi NW of Laporte	60	5.3	65.4	11.5		0.032				
S114-1	Poudre Valley Canal near Ted's Place	63	17.5	36.4		5.1	0.2		86.3		
-2	" Side of hill -- shale	63	5.0	46.9		6.3	0.06		13.3		
-3	" Bottom of canal -- shale	63	2.5	55.7		5.9	0.04		7.8		
S38-1	Dakota fm -- 4.0 mi NW of Laporte	60	64.1	0.6	17.8			0.001	43.8	70	
-2	"	60	56.5	1.6	10.5			0.003	86.1	110	
S52-2	Greenacre Ranch near Waverly	60	50.4	1.6	78.0		0.007		82.9	60	
S31-1	Playa Lake deposit (Wyble) N of Wellington	60	57.7	1.8		8.6		0.002	32.8	110	*
-2	White ash (Wyble) ?	60	4.0	1.1	269.3						
S33-1	E. F. Munroe -- 18 mi N of Fort Collins	60	73.3	3.1	189.0		0.009		82.7	145	*
-2	"	60	78.2	2.0		5.0		0.001	47.1	165	*
-3	"	61	80.0	3.1	30.0						
S51-4	E. F. Munroe -- used in Smith Pond near Fort Collins	61	85.0	1.7	84.4						
S52-7	E. F. Munroe -- black shale above S33 bentonite	60	12.3	56.7	18.4						
-8	E. F. Munroe -- shale between bentonite beds	60	6.0	77.7	194.0						
-9	E. F. Munroe -- valley alluvium E of S33 bentonite	60	30.5	17.5	32.3		0.04		40.7	20	
-10	"	60	19.5	24.6	97.3						
S52-1	Warren Livestock (Wyble) 25 mi N of Fort Collins	60	61.0	3.7	78.0		0.007		82.9	60	*
-3	" 6' layer under 15' overburden	60	12.5	7.0	185.0						
-4	" 4' layer of white clay	60	33.3	16.3	159.0		0.02		93.1	50	
-5	" 3' layer of grey clay	60	14.5	4.7	200.0		0.05		97.7	90	
-6	" 5' layer of white clay	60	32.5	38.7	145.1						
-11	" 4' layer N of road	60	40.5	15.6	98.2		0.07		83.0	70	
-12	" 4' layer 200' above N road	60	48.0	8.3	66.7		0.03		83.1	60	
-13	" 12' layer 300' above N road	60	39.0	7.4	79.8		0.04		83.5	55	
-14	" Directly under white cap	60	31.3	8.6	79.0		0.09			50	
-15	" White cap	60	5.0	46.9	90.0						
-16	" 100' S of road	60	47.0	9.7	72.7		0.06			70	
-17	" South of road	60	45.0	9.3	42.5		0.04			55	
-18	" South side of road	60	45.8	2.2	66.4		0.03		99.0	75	
S51-3	Warren -- used in Smith Pond near Fort Collins	61	34.0	15.1	16.4						
S77-1	C. G. Schrader -- near Rockport	60	34.5	4.6	42.2		0.04		38.7	35	
-2	"	60	35.3	8.8	35.0		0.03		46.0	40	

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* See Table III for results of chemical and mineralogical testing of these samples

TABLE II

Sheet 6 of 9

LABORATORY TEST DATA

Lab No.	Name and Location	Year Tested	Colloidal Yield %	Grit Content %	Permeability Tests				Mixing Index %	Swell Index %	Add'l Testing
					Filter (ml/min)		Layer (ft/day)				
					> 10	< 10	> 0.005	< 0.005			
SOUTH PLATTE RIVER BASIN (Continued)											
S53-1	White Rose Coal Mine near Carr	60	46.5	0.9	78.6		0.04		35.8	30	*
-2	-- E side of Hy 87 on S side Lone Tree Cr. near Carr	60	35.8	8.7	39.2		0.06		25.3	35	
S103-1	Jake Croissant -- county pit 1.5 mi SE of Hardin	62	25.0	4.1	14.7		0.049		14.7	10	
S36-1	C. G. Schrader -- N of Fort Morgan	60	48.9	2.6	28.9		0.02		100.0	100	
-2	"	60	43.7	2.6	13.3			0.004	99.1	110	
-3	"	60	54.5 ✓	2.5	18.0		0.01		53.2	50	
-4	" Pawneee Buttes N of Ft. Morgan	60	52.3 ✓	1.7	26.7			0.004	47.0	130	*
-5	" Pawnee Buttes N of Ft. Morgan	60	57.6 ✓	5.5	48.7			0.0009	77.9	100	*
-6	" Road cut near Keota	60	1.8	68.1	55.7		0.07				
-7	" White ash	60	1.3	13.5	77.2		0.106				
-8	" Grey clay	60	60.0 ✓	6.3	97.5		0.085				
S74-1	Bartelle Ranch -- 9 mi N of Ft. Morgan	60	42.5	1.1	74.6		0.019		32.7	70	
-2	" 3/4 mi E of S74-1	60	38.8	1.2	74.6		0.019		32.7	70	*
-3	" 50' up from stake (Schrader No.3)	61	35.8	6.4	111.3					70	
-4	" 75' up from stake (Schrader No.4)	61	38.8	2.8	31.0					60	
-5	" Schrader No. 5	61	40.0 ✓	1.5	119.1						
-6	" 1 mi W of Hy 52	61	10.8	25.1	12.0		0.114				
-7	" 1 mi W of Hy 52	61	15.0	16.2	35.5						
-8	" Schrader No. 6 -- 10' trench	61	34.5	10.0	118.0						
-9	" Schrader No. 7 -- 800' E of road	61	43.0 ✓	0.8	117.0					85	
-10	" Schrader No. 8 -- W of road	61	36.8	1.6	52.8					80	
S63-1	-- 2.5 mi S on Hy 71 from Last Chance	60	41.9 ✓	1.7	12.1			0.004	24.3	60	*
S71-1	-- W side of Hy 63 8 mi N of Akron	60	35.0	16.4	19.5		0.06		25.7	25	
S70-4	-- in old brick pit 1 mi N of Iliff	60	29.8	12.7	12.1		0.04		31.8	30	
S70-1	J. P. McKenzie Ranch (Yahn) 9 mi N of Iliff	60	4.0	43.4	54.4						
-2	" 300 yds N of S70-1, near Iliff	60	13.8	25.8	38.0						
-3	" Badlands near ranch, near Iliff	60	3.8	57.9	94.0						
SAN LUIS VALLEY											
S94-1	Alkali flats -- 13 mi E of Saguache	61	68.0	1.4		0.9		0.0	28.6	120	*
S30-1	Joe White -- near La Garita	60	24.9	48.0	10.8		0.057				
S40-1	-- (Chapman) near Center	60	3.3	73.7							
-2	- (Chapman) NE of Hooper	61	42.8	6.3		1.0		0.0004	100.0	50	
-3	-- (Chapman) 3 mi E and 6 mi N of Center	62	41.9	22.3		0.8		0.0001		25	
S40-4	Cowan lease -- NE of Hooper Center of E pit No. 1	62	47.5	4.6		0.7		0.0003	93.0	50	
-5	" Pit No. 2	62	25.0	21.8		2.5		0.0002	80.0	30	
-6	" Ridge	62	23.2	40.6		0.9		0.0002	99.0	15	
-7	" W of pit No. 2	62	38.8	20.3		1.2		0.0	97.0	20	

Compiled by G. A. Lutz and L. G. White

* See Table III for results of chemical and mineralogical testing of these samples

TABLE II

Sheet 7 of 9

LABORATORY TEST DATA

Lab No.	Name and Location	Year Tested	Colloidal Yield %	Grit Content %	Permeability Tests: Filter (ml/min) > 10	Permeability Tests: Filter (ml/min) < 10	Permeability Tests: Layer (ft/day) > 0.005	Permeability Tests: Layer (ft/day) < 0.005	Mixing Index %	Swell Index %	Add'l Testing
	SAN LUIS VALLEY (Continued)										
S40-8	Cowan lease NE of Hooper W of pit No. 2	62	47.5	16.9		1.0		0.0	54.0	50	
-9	" 4' hole in pit No. 2	62	20.0	25.5		1.9		0.0003	42.0	60	
-10	" Center of pit No. 1	62	45.0	6.2		1.3		0.0003	91.0	40	
-11	" 100' N in pit No. 1	62	45.0	8.4		1.1		0.0	71.0	55	
-12	" 200' N in pit No. 1	62	47.5	7.8		0.9		0.0007	95.0	40	
-13	" 100' S in pit No. 1	62	30.0	14.8		1.4		0.0003	53.0	60	
-14	" 200' S in pit No. 1	62	32.5	13.3		1.0		0.0004	76.0	50	
-15	" 300' S in pit No. 1	62	37.5	11.3		1.0		0.0003	95.0	50	
-16	" 100' W in pit No. 1	62	37.5	8.5		0.8		0.0003	74.0	40	
-17	" 100' E in pit No. 1	62	32.5	27.4		0.9		0.0003	72.0	50	
-18	" On road into pits	62	10.0	52.9		3.9		0.0003	70.0	0	
-19	" Sample of stockpile	62	42.5	8.5		1.2		0.0006	93.8	60	*
-20	" N of east pit	63	23.8	14.9		4.0	0.015			5	
-21	" S side of lake (west)	63	18.8	43.8	24.5		0.061			0	
S104-1	Cowan lease -- NE of Hooper	62	57.0	3.5		0.6					
S100-1	Trinchera Ranch near Fort Garland (pink)	61	26.7	46.8		3.3	0.011		69.2	10	
-2	" (brown)	61	37.3	36.5		6.4	0.070		41.0	30	
-3	" (white)	61	61.0	34.0		6.2	0.067		94.8	50	
S110-1	L. A. Murphy -- near Mesita	63	47.5	2.0		4.4	0.018		98.3	225	
S93-1	J. H. Smith -- 8 mi W of Mesita	61	73.5	3.9		6.4	0.017		99.5	240	*
-2	Braiden-Rivera -- E of Manassa	61	44.9	44.8	26.0		0.450		93.5	190	
-3	"	61	25.2	40.1	25.4		0.690		67.9	170	
S31-3	-- 1 mi S of Creede	60	36.2	2.7		5.3		0.001	32.5	80	
	COLORADO RIVER BASIN										
S90-1	Cut on Hy 34 (R. Fisher) 3 mi NW of Granby	61	31.9	9.4		1.1		0.0	18.3	120	*
-2	"	61	29.9	15.4		1.3		0.0	28.6	120	
S97-1	C. A. Forster (grn to grey) near Bond	61	38.6	16.6	11.0		0.008		60.4	20	*
S43-1	Burton-Tuttle Ranch NW of Aspen	61	36.0	7.0	17.1		0.009		46.9	55	*
S96-1	J. A. McNulty -- NE of Carbondale	61	23.0	26.0	19.7		0.100		60.4	20	
-2	"	61	13.6	6.3	47.5		0.211		6.9	20	
-3	"	61	17.1	6.3	25.8		0.024		17.6	20	
-6	" 0-2' depth	62	22.5	8.1		4.1	0.027		28.6	40	
-7	" 2'-8' depth	62	30.0	1.4		4.6	0.031		54.8	50	*
-4	Hemann -- near Aspen	61	27.7	6.2		6.4	0.025		30.9	20	
S108-1	-- (Yingst - CSM) 8 mi W of Colbran	62	11.3	40.1		2.2		0.002		35	
79-1	W. C. Rump -- Redlands area W of Grand Junction	61	46.5	6.5		1.9		0.0	20.9	190	*
-2		61	45.6	8.7		2.3		0.0	18.0	190	

Compiled by G. A. Lutz and L. G. White

* See Table III for results of chemical and mineralogical testing of these samples

TABLE II

Sheet 8 of 9

LABORATORY TEST DATA

Lab No.	Name and Location	Year Tested	Colloidal Yield %	Grit Content %	Permeability Tests Filter (ml/min) > 10	Permeability Tests Filter (ml/min) < 10	Permeability Tests Layer (ft/day) > 0.005	Permeability Tests Layer (ft/day) < 0.005	Mixing Index %	Swell Index %	Add'l Testing
COLORADO RIVER BASIN (Continued)											
S42-1	W. C. Rump - Redlands Area W of Grand Junction	60	47.2	9.4		1.5		0.0	14.7	170	*
-2	Redlands Water and Power Co. W of Grand Junction	60	44.1	9.4		3.6		0.0009	37.5	120	*
-3	" Lime Kiln Gulch	60	31.1	10.6		3.4		0.0007	27.5	90	
-4	" Top layer	61	45.8	4.5		2.3		0.002	13.5	270	*
-5	" Lower layer	61	33.5	2.1		2.1		0.001	11.9	175	
-6	L. J. Kelly claims -- Jacob's Ladder rd SW of Grand Junction	61	52.4	4.0		1.0		0.0	0.9	700	
-7	" Above limestone layer	61	70.5	3.0		1.2		0.0	7.1	800	*
-8	L. J. Kelley claims	62	65.0	1.8		0.9		0.0	11.9	450	
-9	"	62	47.0	5.9		1.3		0.0	46.1	320	
S113-1	L. J. Kelley claims	63	42.5	11.5		1.6		0.0002	16.1	215	
-2	"	63	41.3	6.5		2.5		0.0001	40.9	175	
-3	"	63	67.5	1.0		1.0		0.0	10.6	560	
-4	"	63	42.5	10.7		1.4		0.0001	26.1	205	
-5	"	63	42.5	7.5		0.9		0.0	8.5	400	
-6	"	63	15.0	13.8		2.2		0.001	14.0	140	
-7	"	63	43.8	7.1		1.5		0.0002	43.6	175	
S72-1	A. N. Crawford -- 6 mi S of Austin	60	60.8	7.3		10.0		0.001	46.1	130	*
-2	J. W. Peak -- near Montrose	64	70.0	15.2		5.0		0.0007		140	
S21-3	Marshall Pass clay -- 6 mi E of Sargents	61	16.4	39.7		2.9		0.0006	53.5	25	*
-2	-- (Mealy) -- near Gunnison	61	7.1	41.9	18.1					-15	
-4	-- (Mealy) --near Gunnison	62	20.4	47.5	95.3		0.200		30		
-5	P. Vickers -- near Lake City	63	22.5	33.7	58.6		0.14				
-6	Crested Butte - Lost Canyon Area	63	8.8	18.2		3.0	0.3		99.6	120	
S84-1	D. Rowan (Cornforth) -- W of Olathe	61	43.5	7.9		6.9		0.002	29.5	230	*
SAN JUAN RIVER BASIN											
S101-1	I. F. Flora -- 25 mi W of Pleasant View	61	67.8	0.4		0.9		0.0	9.5	500	
-2	"	61	54.4	5.9		1.1		0.0	11.4	370	
-3	"	61	37.5	5.1		1.3		0.0	12.1	220	
-4	"	61	33.6	15.3		1.2		0.0	7.5	180	
S92-1	S. J. McCrosky (Walls) 30 mi N of Durango	61	11.6	19.6	19.1				68.0	0	
-2	" 3' to 5' depth	61	27.5	9.4	37.9				33.4	50	
S115-1	BLM Deposit 7 mi W Norwood	63	30.0	8.8		7.8	0.12		87.8	80	
YAMPA-WHITE RIVER BASIN											
S99-1	Calkins (Palmer) -- 1 mi NW of Steamboat Sprgs.	61	40.2	8.5	17.5		0.034		22.6	30	
S88-2	Wyman (Gregory) -- 15 mi S of Maybell	61	36.8	6.2		1.4		0.0	29.1	300	
-3	Wasatch (?)	61	47.0	11.6		6.1		0.0	21.7	220	*

Compiled by G. A. Lutz and L. G. White

* See Table III for results of chemical and mineralogical testing of these samples

TABLE II

Sheet 9 of 9

LABORATORY TEST DATA

Lab No.	Name and Location	Year Tested	Colloidal Yield %	Grit Content %	Permeability Tests				Mixing Index %	Swell Index %	Add'l Testing
					Filter (ml/min)		Layer (ft/day)				
					> 10	< 10	> 0.005	< 0.005			
YAMPA-WHITE RIVER BASIN (Continued)											
S88-1	Preese (Gregory) -- 16 mi S of Maybell	61	33.1	8.0		2.3		0.0	43.1	100	
-4	" Composite of white	61	53.8	5.9		2.3		0.0007	37.6	115	
-5	" Composite under white	61	20.6	6.4		4.2		0.0009	34.1	50	*
-6	" Yellow in middle layer	61	16.7	20.7		4.7		0.0005	67.1	100	
-7	" Above yellow below black	61	47.7	10.7		2.6		0.001	67.0	105	
-8	" Above black	61	49.7	2.9		2.3		0.0004	56.1	125	
-9	H. Williams -- 15 mi S of Maybell	61	62.3	3.2		1.8		0.0008	30.4	450	*
-10	"	61	51.5	18.3		1.6		0.0006	38.9	420	*
S85-1	I. R. Beckett -- near Craig	61	12.1	47.7	11.1		0.030			-10	
S75-1	-- (Ball) -- near Meeker	60	26.0	8.6		2.8		0.0001		40	
-2	" Reddish brown clay	60	47.8	7.7		5.2		0.0002		35	
-3	" Grey to greenish clay	60	11.6	3.8		3.3		0.0008		35	
-4	-- (Sedgley) -- cut on Hy 132, 8 mi E of Meeker	61	16.3	45.3	12.7		0.039		50.6	20	
-5	"	61	16.3	48.7	12.8		0.060		10.6	0	
-6	J. Urruty -- 20 mi E of Meeker	61	33.4	32.4	19.7		0.024		66.6	70	
-7	M. Villa -- near Meeker	62	20.0	5.0		9.6	0.018		30.0	20	
S91-1	Stedtman Mesa -- 25 mi E Rangely	61	64.0	0.9		7.0		0.0006	45.9	120	
-2	" Exposed formation	61	36.0	5.8		2.9		0.0005	40.1	115	*
-3	BLM (E of Murdock) 25 mi E of Rangely	61	41.7	8.6	10.6		0.042		42.3	55	
NORTH PLATTE RIVER BASIN											
S89-1	John Colter 14 mi E of Walden	62	53.7	5.7		6.2		0.005	14.7	290	
-2	" Auger hole sample	62	72.2	1.0		4.0		0.0004	16.6	330	
-3	"	62	59.4	3.7		3.6		0.0	12.7	420	
-4	" Pit No. 1 (Southernmost)	62	63.8	6.1	10.7			0.0006	17.9	180	
-5	" Pit No. 2	62	69.6	2.0		4.1		0.002	10.0	300	*
-6	" Pit No. 3	62	65.3	2.1		2.7		0.0	6.3	360	
-7	" Pit No. 4 (Northernmost)	62	54.2	0.9		1.0		0.0	4.3	620	
S109-1	N Michigan Dam SE of Walden	63	15.0	52.8		4.5	0.150			30	

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* See Table III for results of chemical and mineralogical testing of these samples

TABLE III

Sheet 1 of 2

CHEMICAL AND MINERALOGICAL DATA

Deposit Name	Lab No.	Cation Exchange Capacity meq/100gm	Exchangeable Cations Meq/100gm			Water Soluble Cations meq/100gm			Exchangeable Sodium Percentage	$CaCO_3$ Equiv. %	pH (1-5) Extract	X-ray Analysis				
												Major Clays				Main Non-clay Minerals
			Na	K	Ca + Mg	Na	K	Ca + Mg				Mont	Kaol	Ill	Mix	
ARKANSAS RIVER BASIN																
Poncha	S48-1	82.1	22.4	1.2	58.5	15.1	0.1	4.3	27.3	7.5	8.5	x				gyp, qtz
Lamberg	S49-3	101.1	24.2	1.5	75.4	2.2	< 0.1	0.2	23.8	0.5	8.5	x				feld
"	S49-8	103.8	24.7	1.2	77.9	2.2	< 0.1	0.7	23.8	0.8	8.8	x				feld, qtz
Kessler	S34-1	103.1	8.7	1.8	92.6	2.2	0.1	1.7	8.4	1.0	8.1	x				MnO_2
"	S34-6	97.3	5.4	1.9	90.0	1.6	0.1	2.4	5.5	1.0	7.8	x				MnO_2
Westcliffe	S47-1	64.4	2.5	4.3	57.6	0.3	< 0.1	0.5	3.9	1.1	8.1	x				
Dilley	S28-2	40.2	10.4	2.3	27.5	9.4	0.3	3.6	25.9	17.1	8.8	x			x	qtz,calc,plag
"	S28-7	41.9	9.9	1.9	30.1	6.4	0.2	4.5	23.6	11.0	9.0	x				qtz, feld
Mahan	S73-2	67.4	0.3	0.8	63.3	0.1	< 0.1	0.5	0.5	9.4	8.3	x				calc, feld
Welte	S60-4	38.3	0.3	1.4	36.6	0.2	0.1	4.9	0.9	2.1	7.5					
School	S44-4	50.0	24.1	2.2	23.7	15.3	0.2	1.8	48.2	1.1	8.7	Na				qtz, feld
"	S44-32	66.5	30.0	1.7	34.8	15.4	0.1	2.0	45.1	0.4	8.6	x				gyp,feld,qtz
Wagner	S45-1	87.5	10.6	1.1	75.8	19.6	0.2	23.7	12.1	0.0	6.9	x	some			gyp, qtz
Stough	S44-21	62.7	23.2	1.4	38.1	6.6	0.1	0.4	37.0	1.4	8.9	x				qtz, feld
SOUTH PLATTE RIVER BASIN																
Stevens	S62-1	19.9	0.6	0.9	18.4	0.1	< 0.1	0.2	2.7	0.0	8.1		x	x		qtz
"	S62-2	9.5	0.2	0.4	8.9	0.1	< 0.1	< 0.1	2.6	0.2	7.6		x			mostly qtz
Cox	S56-1	16.6	0.2	0.7	15.7	0.1	0.1	< 0.1	1.4	0.0	5.6	x	Tr	Tr		qtz,feld,calc
Bennett	S67-2	12.5	0.4	0.3	11.8	0.1	< 0.1	< 0.1	3.0	0.0	7.8		x			1/2 qtz
Lindsey	S68-1	12.2	0.2	0.3	11.7	< 0.1	< 0.1	< 0.1	1.3	0.0	7.5		x	x		mostly qtz
Strainland	S37-2	27.2	0.4	1.0	25.8	0.1	< 0.1	< 0.1	1.6	0.3	7.1	x	x			mostly qtz
Conda	S37-5	34.0	0.7	1.0	32.3	0.1	< 0.1	0.1	2.1	0.3	8.0	x	Tr	Tr		qtz
"	S37-11	36.6	1.2	0.5	34.9	0.3	< 0.1	0.4	3.3	0.5	7.8	x		Tr	Tr	qtz, chlor
Clover B	S55-1	22.3	1.4	0.7	20.2	1.3	< 0.1	0.7	6.6	3.8	8.4			x		qtz,chlor,feld
Brick P	S54-1	24.7	0.6	0.8	23.3	1.0	0.1	3.8	2.7	2.7	7.7	x		x		qtz,feld,chlor
N of Well.	S31-1	38.1	0.4	4.0	33.7	0.1	0.1	0.4	1.0	0.8	7.9		x	x		qtz, feld
Munroe	S33-1	78.3	0.8	1.2	76.3	0.8	0.2	5.9	1.0	0.0	4.1	x				gyp,plag,calc
"	S33-2	78.3	1.6	1.7	75.0	1.2	0.2	6.2	2.1	1.1	7.9	x				gyp,plag,calc
Warren	S52-1	49.5	0.5	2.8	46.2	0.2	0.2	6.5	0.9	2.1	6.6	x				qtz, feld
W Rose	S53-1	40.0	0.3	0.6	39.1	0.6	0.1	17.7	0.8	0.2	7.2	x				qtz,gyp,feld
Pawnee	S36-4	77.2	2.5	3.3	71.4	0.5	0.1	0.4	3.3	1.1	8.0	x				qtz
"	S36-5	50.6	3.2	3.7	43.7	1.8	0.1	2.4	6.3	0.1	7.5	x		x		qtz,gyp,feld
Bartelle	S74-2	34.5	1.3	1.1	32.1	3.7	0.1	11.8	3.7	3.6	7.7	x	x	x		qtz,chlor,plag
L. Chance	S63-1	27.2	1.2	0.9	25.1	0.2	< 0.1	< 0.1	4.3	3.9	8.7	x	x			qtz,chlor,feld

Compiled by R. Dirmeyer and G. A. Lutz

TABLE III

Sheet 2 of 2

CHEMICAL AND MINERALOGICAL DATA

Deposit Name	Lab No.	Cation Exchange Capacity meq/100gm	Exchangeable Cation Meq/100gm			Water Soluble Cation Meq/100gm			Exchangeable Sodium Percentage	$CaCO_3$ Equiv. %	pH (1-5) Extract	X-ray Analysis				
												Major Clays				Main Non-clay Minerals
			Na	K	Ca + Mg	Na	K	Ca + Mg				Mont	Kaol	Ill	Mix	
SAN LUIS VALLEY																
Alkali	S94-1	33.9	29.7	2.7	1.5	45.7	1.3	0.3	87.6	41.7	9.5					
Cowan	S40-19	22.2	9.3	5.6	7.3	26.1	1.5	0.0	41.9	32.3	10.1			x		Calc,feld,qtz
Smith	S93-1	87.0	5.5	1.1	80.4	0.7	< 0.1	0.8	6.3	0.9	8.5	x				hi feld
COLORADO RIVER BASIN																
Granby	S90-1	43.5	16.4	10.2	16.9	2.8	0.1	0.6	37.7	2.8	8.9	x		x	x	mica,qtz,feld
Forster	S97-1	16.5	0.3	0.4	15.8	0.1	< 0.1	0.8	1.8	0.9	8.4		x			high qtz
Tuttle	S43-1	15.0	0.5	0.4	14.1	0.5	< 0.1	3.0	3.3	16.0	8.2		Tr	x		qtz,dol,feld
McNulty	S96-7	56.5	0.5	0.6	55.4	0.1	0.0	0.3	0.9	0.2	7.7	x			x	hi qtz, feld
Rump	S79-1	65.4	38.8	1.9	24.2	2.4	< 0.1	0.4	59.3	7.2	9.6	x				hi qtz, feld
Rump	S42-1	65.7	38.3	1.5	25.9	1.9	0.0	0.3	58.3	5.3	9.5	x				qtz, calc
Redlands	S42-2	50.7	34.7	1.3	14.7	19.7	0.1	1.8	64.5	5.6	9.0	x	Tr			qtz,calc,feld
"	S42-4	56.0	28.1	1.3	26.6	2.3	< 0.1	0.6	50.2	7.1	9.5	x				hi qtz, calc
Kelley	S42-7	75.2	45.3	2.2	27.7	2.7	0.1	1.0	60.2	4.5	9.5	x				hi qtz,calc,feld
Crawford	S72-1	57.9	21.5	2.1	34.3	78.0	0.9	60.7	37.0	0.9	7.7	Na	Tr			qtz, feld
M. Pass	S21-3	41.9	2.7	11.1	28.1	0.1	0.1	0.3	6.4	0.5	6.1	x		x		feld, qtz
Rowan	S84-1	54.9	41.1	1.9	11.9	39.9	0.3	2.5	74.9	3.1	9.1	x	Tr			qtz
YAMPA-WHITE RIVER BASIN																
Wyman	S88-3	42.1	7.7	1.2	33.2	16.8	0.2	4.5	18.3	0.5	7.5	x		x		qtz,feld,chlor
Preese	S88-5	36.2	14.8	0.8	20.6	11.0	0.1	0.8	40.8	0.9	8.6	x	x	x		hi qtz
Williams	S88-9 & 10	58.4	37.2	1.6	19.6	6.1	0.1	0.6	63.7	0.0	9.2	x		x		feld, qtz
Stedtman	S91-2	39.4	26.6	1.1	11.7	4.9	< 0.1	0.6	67.5	1.0	8.4	x		x		hi qtz
NORTH PLATTE RIVER BASIN																
Colter	S89-5	87.0	30.1	1.4	55.5	23.6	0.1	9.7	34.6	3.8	8.1	x				gyp, qtz, dol, mica

Compiled by R. Dirmeyer and G. A. Lutz

Minerals

Mont	Montmorillonite
Kaol	Kaolinite
Ill	Illite
Mix	Mixture of clays
Qtz	Quartz
Gyp	Gypsum
Feld	Feldspar
Calc	Calcite
Chlor	Chlorite
Dol	Dolomite
Tr	Trace

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