PROGRESS REPORT OF CLAY SEALING INVESTIGATIONS DURING 1961

by

R. D. Dirmeyer, Jr.
Engineering Research
Colorado State University

Prepared for the
Colorado Water Conservation Board

COLORADO STATE UNIVERSITY EXPERIMENT STATION
CIVIL ENGINEERING SECTION
FORT COLLINS, COLORADO

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ADVANCE SUMMARY

The research and development work during 1961 in regard to the use of Colorado clays for sealing irrigation canals and reservoirs is summarized in this report. The Colorado State University work has included: (1) sampling of clay deposits, (2) laboratory testing of clay samples, (3) assistance in development of clay deposits, and (4) evaluation of field tests using Colorado clays in canals and reservoirs. The results of this work are summarized in Figure I and Tables I(a), I(b), I(c), II, III, IV and V at the end of this report.

The work started or completed in each of the major river areas of Colorado is summarized below:

1. Arkansas River Area -- This has been the most active area in the State for clay-sealing work -- especially the area around Salida. Several sources of an excellent quality bentonite or clay have been located and developed in this area. Experienced contractor services are available for installation work in canals and ponds. Many favorable installations have been made -- especially in the area between Salida and Buena Vista. (See Figure I and Tables I(a) and III.)

2. Colorado River Area -- Several sources of an excellent quality bentonite or clay have been located in the vicinity of Grand Junction and Meeker, Colorado. Favorable prospects have been located in several additional locations within the drainage area. Contractor services, specializing in clay-sealing work, are not yet available. Only a few installations have been made, but the need for canal and pond sealing is well recognized in this general area. (See Figure I and Tables I(b) and IV.)

3. North Platte River Area (North Park) -- One source of an excellent quality bentonite has been located, but it is not developed yet. Contractor services, specializing in clay-sealing work, are not available. The interest in canal and pond sealing is just starting to develop in this area. (See Figure I and Table I(c).)

4. Rio Grande River Area (San Luis Valley) -- Several excellent quality, but undeveloped, clay deposits have been located. No local contractor is specializing in clay-sealing work, but the northern part of the valley is being serviced and supplied from the nearby Salida area. A number of successful installations have been made in canals and ponds in the north end of the valley. (See Figure I and Tables I(b) and IV.)

5. San Juan River Area -- The interest in canal and pond sealing is well-developed in this area, but so far only borderline quality clays have been found in the immediate area. The Salida bentonite has been used in one canal and several ponds in the Durango-Pagosa Springs area. One excellent clay deposit prospect has been located west of Durango by a local prospector. (See Figure I and Tables I(b) and IV.)

6. South Platte River Area -- Several fair to borderline quality clays have been located in this area -- mainly along the foothills and north of Fort Morgan. Several contractors are interested in the work and additional installations are planned. Most of the past work in this area has involved Wyoming bentonite. Additional development work is needed since the past work has produced only mediocre results in this area. (See Figure I and Tables I(c), III and V.)

ACKNOWLEDGMENTS

The research and development work, to date, as outlined in this progress report has been sponsored and financed initially by the Colorado Water Conservation Board and the Southeastern Colorado Water Conservancy District, and presently by the State of Colorado through the Colorado State University Experiment Station.

An additional and important source of sponsorship and financial support has been provided by individuals, irrigation companies, and private companies that are cooperating in the Colorado State University investigations. The financial part of this cooperative support has been directed into the development of clay deposits and installation of field trials in canals and ponds, all of which has added greatly to the accomplishment of project objectives.

Grateful mention also is made of the cooperation and encouragement supplied by individuals in Soil Conservation and County Extension offices in Colorado -- especially in the irrigated areas of Colorado.

Finally, these acknowledgments would be incomplete without mentioning that the Colorado State University phases of the work, to date, have been completed on a teamwork basis. The departments and individuals contributing to the work herein are listed below:

Civil Engineering Department

M. M. Skinner — R. T. Shen
G. A. Lutz — L. G. White

Agronomy (Soils) Department

W. R. Schmehl — R. E. Danielson
Hunter Follett

Geology Department

D. W. Harris — M. E. McCallum
E. N. Wolff — D. E. White

Agricultural Engineering Department

R. W. Hansen

INTRODUCTION

With ever-increasing demands being placed on the water supplies available in Colorado, improved efficiency of use is a necessity. Many research and development activities are now aimed at this problem. For example, consider current efforts in (a) the desalting of brackish water, (b) the reduction of evaporation from water surfaces and from high water table areas supporting low-benefit vegetation, (c) the increase of run-off from treated watershed areas, (d) the development and storage of water underground, and (e) the reduction of seepage losses from canals and reservoirs. Many state and federal agencies, private companies and water districts, and universities and colleges, including Colorado State University, are engaged in these activities.

This progress report summarizes the research and development work accomplished during 1961 at Colorado State University in regard to the use of Colorado clays for sealing canals and reservoirs. This project, commonly called the Colorado State University Bentonite Project, has two general objectives: (a) to inventory the clay resource (including bentonite) of Colorado, and (b) to develop methods of utilizing the local clays in sealing canals and reservoirs in Colorado. Thus, two important justifications for this state-funded work are (a) new industry development, and (b) conservation of water.

The major project activities were started in July 1960 and are scheduled for completion by July 1963. This, therefore, is a report of progress to the half-way point in the investigations.

Since the investigations are not complete at this time, we welcome review comments, suggestions, corrections, or additions to this report. In some respects, this is a rough draft outline of the final report. Please, therefore, if you can possibly spare the time, jot down comments as you read this report and send them to us. Pencil notes will be acceptable and greatly appreciated.

THE SEEPAGE PROBLEM

Seepage loss from canals and reservoirs is surprisingly great in Colorado, and a serious problem. During the current investigations, some 100 canals and 50 ponds have been examined. The canal losses were found to range from 100 per cent (or total loss) in some systems late in the summer to one outstanding minimum of less than 3 per cent in 8 miles of canal. The pond losses ranged from as high as total loss over-night to a minimum of about 1-inch per day drop in water level. Seepage loss into leaky bed and bank materials obviously is not the only source of loss but undoubtedly the major source--especially in the high loss cases.

It is true that the seepage water is not physically destroyed, and undoubtedly some of the loss water returns to the main river channel; but this water after loss is seldom available for use by those who store, divert or pay for it. With favorable groundwater reservoir conditions, recovery of seepage loss water may be feasible, but usually not without additional expenditures for equipment and power. In many instances, the seepage water may flood and damage land in its return flow path to the river, part of it may be used and transpired by swamp and other non-crop plants, part of it may evaporate directly from seep-flooded areas, and almost invariably it will pick up an additional load of dissolved salts.

One promising potential benefit of seepage in Colorado relates to the possibilities of planned groundwater recharge operations based on a seepage loss from infiltration facilities, including canals and reservoirs. The various technical and legal problems involved in this possibility are now under study at Colorado State University.

In considering all aspects of the seepage loss problem in Colorado, it is estimated that the direct and indirect losses are as follows:

Assumed annual irrigation diversions	10,000,000 AF
Assumed canal and reservoir seepage loss . .	25 %
Annual loss of irrigation water	2,500,000 AF
Estimated value of loss water	$5,000,000/yr
Estimated indirect or seep-damage losses	$5,000,000/yr
Total estimates losses	$10,000,000/yr

As to future prospects, it is likely that the present trend toward an increase in seepage losses will continue. This trend is attributed to the gradual elimination of sediment or mud from irrigation water by construction of upstream reservoirs. It is a common observation in areas such as below John Martin Reservoir near Lamar, Colorado that clear water will seep from canals and irrigated fields at faster rates than muddy water. Another important factor relates to the increasing amounts of sewage in irrigation waters in Colorado. The typical "foaming" waters, now evident in canals below some Colorado towns, seem to seep away at faster rates than the previous "non-foaming" water supplies.

SEEPAGE CONTROL

Much of the recent lining and sealing of canals and reservoirs in Colorado has been accomplished under two Federal Programs.

The first program is that of the Bureau of Reclamation. Virtually all of the canals and reservoirs constructed by the USBR in Colorado (and elsewhere as well) have included in recent years adequate seepage control measures. In almost all cases, the conventional and time-tested linings of concrete, asphalt and compacted earth have been used. The USBR's Lower Cost Canal Lining Program is including tests of many types of linings and sealers, but to our knowledge no actual construction work has been accomplished recently by the USBR in Colorado with locally-available low-cost clays and methods as described herein.

The second program is the Agricultural Conservation Program of the U.S. Department of Agriculture. This is a cost-sharing program handled by the local Agricultural Stabilization Committee office in each county--with the actual construction work supervised by the Soil Conservation Service office in each area. This program is primarily aimed at aiding individual farmers and ranchers. Thus, the canal and pond lining phase of this program is mainly concerned with on-farm practices, such as concrete slip-form ditch linings. Recently however, and as an important part of the field trial phase reported herein, an increasing number of supply canals and ponds are being sealed with Colorado clays under the Federal Agricultural Conservation Program or cost-sharing program.

While the above-mentioned Federal programs are most important, our general impression after travelling in almost every irrigated area of Colorado is that only the surface of the general canal and reservoir seepage problem has been touched by the current work. Very few irrigation companies or districts in Colorado are accomplishing (or even planning) significant amounts of canal or reservoir lining or sealing work.

Cost, and especially financing, seems to be one retarding factor. When considering the major costs of a comprehensive program of the dependable linings, such as those of concrete or asphalt, many and perhaps most irrigation companies and districts find themselves in a "no-man's-land" for financing--too small for Federal loan programs, such as the Small Projects Act, and too large for the sponsoring irrigation group. Irrigation districts or companies apparently are not directly eligible for Federal cost-sharing support.

One possible answer to the financing problem is for the State of Colorado to activate a construction loan program for water projects, such as offered by Wyoming and Utah.

Another potential answer to the canal and pond lining or sealing problems is to provide truly low-cost methods of sealing irrigation canals and reservoirs that will be within immediate financial reach of irrigation organizations--interim methods such as the clay sealing methods described herein that will save water until hard-surface linings or even pipes can perhaps be afforded.

PREVIOUS CLAY SEALING

In virtually all irrigation areas, flows of muddy flood water usually have been considered as unfavorable. The obvious disadvantages, such as deposition of sand and silt in canals and on irrigated land, usually have been more noticeable than the advantages. Frequently, the advantages, such as canal sealing, have gone unnoticed until canal cleaning or construction of an upstream dam revealed the advantages of muddy water. In any case, nature has provided many excellent examples of previous clay-sealing work.

With flows of muddy water becoming increasingly uncommon in irrigation projects, many irrigation companies and districts have tried "Silting" as a counter-measure to the clear water problems--some with outstanding success but many with little or no visible results of a favorable nature. Apparently, the best results have been obtained where the canal bed and bank material is a coarse sand, gravel, or fractured rock. Commonly, detailed information regarding the application method is available, but pertinent data on the silting material itself is seldom available.

As a related type of work, mention should be made of the significant work now underway in regard to chemical sealants. The USBR is doing an excellent job of encouraging and coordinating this work, which is mostly being done by private companies. Sealants under investigation and development include: SS-13; chevron soil sealant; and several cationic asphalt emulsion materials. Most of these sealants mix readily with water and the sealing action is concentrated in the high seepage loss zones.

SCOPE OF PRESENT INVESTIGATIONS

The present Colorado State University project work is preceded by extensive investigations, started in July 1953, into the sedimenting or float-in use of Wyoming high-swell bentonite for sealing irrigation canals. In one major respect, the present work is an extension of this previous project work--with locally-occurring Colorado clays being substituted for the Wyoming high-swell bentonite. While the Wyoming bentonite is available commercially as a uniform material of essentially known characteristics, the Colorado clays are, for the most part, undeveloped and of unknown and widely varied quality and quantity. Thus, the early part of the current project work has been directed toward an evaluation of the clay resource of Colorado, with increasing emphasis now being placed on the follow-up phase of field trials in canals and ponds. The clay resource evaluations have included both field sampling and laboratory testing.

CLAY SAMPLING

One basic assumption made in setting up the Colorado State University research and development project was that ample deposits of clay, suitable for sealing purposes in canals and reservoirs, could be found in or near each of the major irrigated areas of Colorado. As may be seen in Figure I at the back of this report, considerable progress in finding clay deposits has been made. Additional deposits of suitable clay, however, are still needed in some areas, such as northeastern and southwestern Colorado. Development of the clay deposits is a separate matter, discussed in a later section of this report.

In some instances, especially in the early work, direct prospecting was accomplished by a CSU project geologist, but recently most of the new deposits have been located as result of cooperative help of two types:

1. Individual prospectors -- The response to our newspaper and radio requests for this type of cooperation has been most helpful and productive of clay deposits.

2. SCS and Extension Agents -- Wonderful cooperation has been received from these two sources resulting in the discovery of several very fine clay deposits.

In general, the sampling of clay deposits is of a progressively more detailed nature, closely related to the development work at the deposit. In other words, as the better prospects are explored and opened up, additional sampling is accomplished. The CSU project does the sampling and laboratory testing without charge to the clay contractor, but does not finance the exploration or deposit development.

More detailed information is available from CSU regarding the appearance and other characteristics of a good sealing clay, but briefly the best clays and clay deposits have the following features:

1. They usually occur in bare badland areas with the outcrop surfaces of the better clay deposits being loose and granular (like coarse sawdust) when dry and extremely gummy when wet.

2. The clay or bentonite is found in many colors with red, green, yellow and white being most common. The best clays are commonly very low in sand--almost no grittiness when tasted.

3. The most common geological formations in which the better clays or bentonites occur include: the Morrison formation (some of the bentonite deposits are in uranium claims), the Benton formation, and recent Tertiary formations (one excellent deposit occurs as a crack-filling material in a volcanic cone).

CLAY TESTING

The results of laboratory testing of the clay samples collected thus far in the Colorado State University program are summarized in Tables I(a), (b), (c), and II at the end of this report. As mentioned previously, the clay deposits or sample locations are shown on Figure I . As of January 1, 1962, 237 samples from 99 deposits or sample locations have been tested. Of the total, 112 samples were tested during 1961.

While the test results in the tables are grouped as to favorable and unfavorable, this division is extremely arbitrary and tentative. Actually, only a very few of the samples are of satisfactory reliability. The cross-section samples from stockpiles of mined bentonite usually are considered reliable, but most of the samples are exploration samples from outcrop areas. The test results of the latter type of sample can be expected to vary widely from one sample location to another.

Even with reliable and representative samples, the results of the laboratory testing should be tempered with the knowledge of where and how the clay is to be used. For example, in very coarse rocky materials a gritty clay will often hold better than a pure grit-free clay--to use such a gritty clay for sealing a sandy soil could be wasteful.

For a brief description of the test procedures, see the bottom of Tables I(c) and II. While not infallible nor final, the following test limits are offered for general guidance concerning clays to be used for sealing of canals and reservoirs:

1. Layer permeability-- A permeability of .009 ft/day or less is desirable. As may be seen in the tabulation at the bottom of Table II, the recommended thickness of clay layer increases as the permeability increases.

2. Filter permeability -- A value of 10 ml./min. or less is desirable.

As a note of caution and explanation, the laboratory layer permeability test is run on a loosely-placed layer--compaction of the clay layer or salt treatment, if properly utilized, will lower the permeability of the clay layer. In addition, the filter permeability test is pointed at the float-in applications of clay in canals. Here again proper use of a dispersing agent, such as Calgon, can result in a lower permeability rate.

Although exceptions to the following have been noted, the best sealing clays (as indicated in field trials) usually exhibit the following characteristics:

1. A colloidal yield (clay content) of 30% or more.
2. A grit or sand content (.074 mm or more) of 15 % or less.
3. A swell index (ratio of wet to dry volume of clay) of 100 % or more.
4. A cation-exchange-capacity of 40 meq/ 100 gms or more.
5. An exchangeable-sodium-percentage of 10% or more.
6. Montmorillonite as the dominant clay mineral.
7. A mixability index (ease of mixing) of 50% or more, if the clay is to be useful in float-in (sedimenting) applications.

As to future laboratory work on Colorado clays, all of the testing procedures are still in a process of development and refinement. This work will be intensified and essentially completed during 1962. Samples from new clay deposits and follow-up samples from deposits under development also will be tested. The objective of this work is development of simple reliable test procedures for use by commercial, state and federal laboratories in future evaluations of clays for canal and reservoir sealing purposes.

DEVELOPMENT OF DEPOSITS

Another basic assumption made in setting up the Colorado State University project was that once the deposits of suitable clay were located, they would be developed commercially. Excellent progress in this direction has been made--especially in the Arkansas River and Colorado River areas.

A major part of the development work has been done by local earth-moving contractors--with lesser amounts by irrigation companies, local prospectors, and lease speculators. Since, in general, the market for the clay product, as well as the deposit itself, must be developed, the major tonnage of clay has been sold by those equipped to install as well as mine and process the clay.

As perhaps to be expected in any new industry, the quality of the produced material varies widely. Quality control is needed and those of you that are potential buyers of clay can help by buying on a basis of quality rather than price alone.

In addition to the characteristics discussed previously under CLAY TESTING, a high quality clay will have the following characteristics:

1. Low impurities content -- If the deposit is clean-stripped of overburden materials before mining of the clay, this normally will control this quality problem.

2. Low moisture content -- The clays in the deposits commonly have from 20 to 50 per cent moisture content. Before use the moisture content should be lowered to less than 20 per cent.

With proper mining procedures, the moisture problem and several other problems, such as variability of clay and size of lumps, can be controlled satisfactorily. An adequate mining operation will be characterized by the following:

1. Overburden -- The overburden should be removed over a large area rather than one small or several separate small areas.

2. Air-drying -- During dry weather, the clean-stripped clay layer should be harrowed or loosened to assist in the air-drying process. A south-facing slope will work best for the air-drying process.

3. Stockpiling -- To assist in mixing the clays to obtain a uniform clay product, the clay should be stockpiled after air-drying.

4. Lumps -- With adequate air-drying, most clays will break down to fragments of 1/2-inch or less in diameter. If larger lumps are present, additional processing is needed.

The amount of processing required to produce a uniform clay material for sealing purposes can be reduced significantly by the mining procedure, but since the air-drying operation in the open pit mine is vulnerable to weather, processing equipment for artificial drying, grinding and screening will be desirable in the advanced developments. Limited investigations into processing equipment have been made and one experimental set-up of grinding equipment in a clay processing mill is being observed and evaluated.

As to future work in this regard, when requested, assistance will be provided to clay producers including both laboratory testing and development recommendations. In addition, the possibilities of specifications for clay sealing materials will be explored during the coming year--both with the clay producers and with the SCS, ASC, and Extension people in areas where clay-sealing work is being accomplished with federal cost-sharing assistance.

FIELD TRIALS

A third assumption made in setting up this project was that with deposits located and development begun, trial installations with local clays in canals and reservoirs would be made. As may be seen in Figure I, where the trials are located, and in Tables III, IV, and V, where the results are summarized, significant progress in this respect has been made.

A total of 89 installations are evaluated in this report. Of this total, 38 (26 ditches and 12 ponds) are in Eastern Colorado and 35 (23 ditches and 12 ponds) are in Western Colorado. Those in the San Luis Valley are included in the Western Colorado grouping. The remaining 16 (13 ditches and 3 ponds) were made with Wyoming bentonite rather than Colorado clay.

Significantly, all of the field trials have been made at the expense of the individuals or irrigation companies. In some instances, the clay producer has partially subsidized the field trials and, in many instances, federal cost-sharing has been received. The noteworthy fact is, however, that the bulk of the development work has been accomplished by irrigation people, sufficiently concerned and interested to spend major amounts of their own time and money toward the development of low-cost sealing methods for canals and ponds.

At this half-way point in the evaluations, only tentative conclusions concerning results can be offered. These tentative conclusions, gained from a study of results outlined in Tables III, IV, and V, are listed below:

1. The most favorable results were obtained from installations in rocky to gravelly materials.

2. The most unfavorable results were obtained from installations in silty to fine sand materials.

3. The estimated value of benefits during the first season after installation have, in many instances, equalled or exceeded the costs of installation.

Three general methods of installation (or combinations thereof) have been used in the field installations:

1. Wash-in -- The clay is washed into the head-end of the canal being sealed. The flowing canal water carries the clay to and into the leaky zones.

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

3. Membrane -- The canal section is over-excavated to at least one foot depth and the clay is placed as a continuous membrane. It is then packed and covered with excavated material and/or gravel.

More detailed information on procedure is available by writing to the Colorado State University project.

As to future project activities in regard to trials, the evaluations of existing (and new) trials will be continued. The project emphasis will be on new trials in sandy to silty soils, where major development problems remain at this time.

CONCLUSIONS AND RECOMMENDATIONS

1. Where is clay sealing applicable? The methods under development by this project are aimed primarily at (a) supply canals of irrigation companies and districts, and (b) any canals (district, company or individual) in rocky to gravelly materials of the mountainous sections of Colorado.

2. What is an acceptable clay? This is still being determined, but, in general, we are looking for clays which when placed loose as a layer about 1/2-inch thick will hold water (3-foot depth or more) with the loss restricted to 1-inch or less drop in water level in 24 hours. In addition to this requirement, a clay suitable for wash-in applications in canals should mix easily in flowing water (mixability index of 50 percent or more).

3. What are the recommended methods? Without going into the actual procedures, the initial evaluations indicate that the best methods are:

a. For canals in rocky and gravelly material -- The wash-in and the multiple-dam methods are recommended provided (a) the right clay is used, and (b) follow-up treatments are carried out. The right clay means one that will stay in place under the expected canal conditions. The follow-up treatment (usually 10 percent of initial treatment amount) consists of washing clay in with the first water in the canal each spring for at least two years after the initial treatment. The buried clay membrane method is also recommended but may be quite expensive in rocky areas.

b. For canals in sandy to silty soils -- The buried membrane method, if properly used, is recommended for these soils. The wash-in methods are not yet recommended -- the development work on the latter methods is not complete.

c. For ponds in leaky soils -- The buried membrane method is the recommended one -- although development work on wash-in modifications is still under way. The beaching or water-line erosion is a major problem which requires special treatment for ponds in windy unprotected locations. Piling riprap or extra clay or bentonite in the water-line zone has been used to control this problem of erosion.

4. Where is additional development work needed?

a. Additional deposits of clay are needed especially in the northeastern and southeastern sections of Colorado.

b. Additional evaluation and development of laboratory procedures used for testing the clays is needed to establish reliable tests.

c. Additional development of known clay deposits is needed. Contractor help, both in development and in selling of clay-sealing work, is needed.

d. Additional field trials are needed -- especially in canals located in sandy to silty soils. Contractor help (as mentioned in c above) and installations by irrigation companies and districts are needed.

AVAILABLE PUBLICATIONS

The following publications are available from the Colorado State University Bulletin Room:

1. Mixing Bentonite for Sealing Purposes, Circ. 204 A.

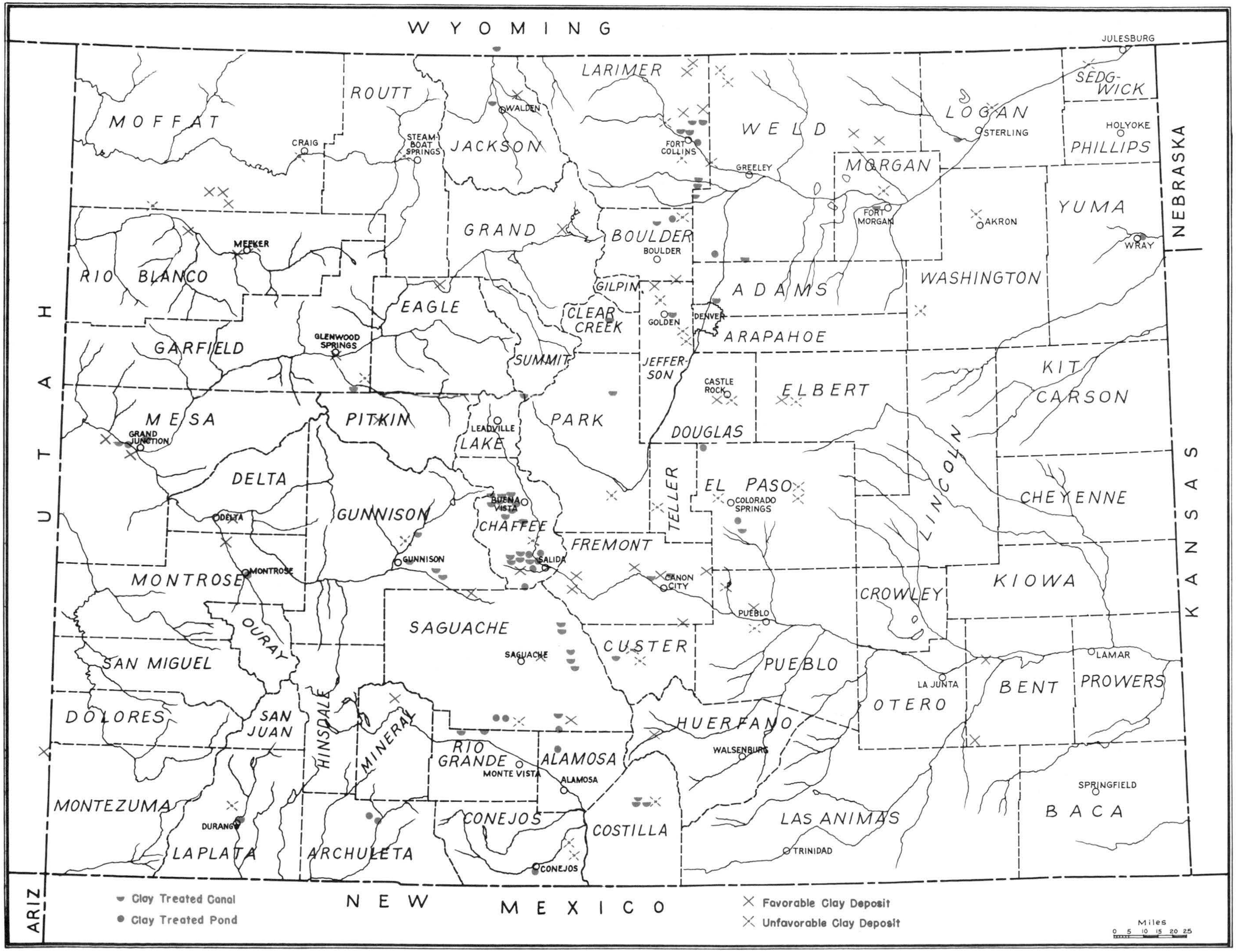
2. Testing Bentonite for Sealing Purposes, Circ. 205A.

3. Sealing Farm Ponds with Bentonite, Circ. 206A.

The above circulars apply, in general, to Wyoming bentonite, but the procedures for the best Colorado clays will be similar. Circular 202A -- Sealing Sandy Ditches with the Bentonite Dispersion Method, and Circular 203A -- Sealing Rocky Ditches with the Bentonite Multiple-Dam Method, are out of print, although possibly the Wyoming Extension Service at Laramie, Wyoming, still has a supply (Wyoming Nos. 158 and 159).

A rewrite of the Rocky Ditch circular has been completed, which relates to methods of using Colorado clays. It is expected to be available for distribution from the Colorado State University Bulletin Room by March 1962.

A limited supply of CER60RDD33, Sediment Sealing of Irrigation Canals (Report of the three-year period of 1957 through 1959) is available at a cost of $2.00/copy. This report is primarily concerned with the use of Wyoming high-swell bentonite, but it also relates the experience with the SS-13 sealant in the Coachella Canal of Southern California.


WYOMING
NEW MEXICO
UTAH
NEBRASKA
KANSAS
ARIZ
MOFFAT
ROUTT
JACKSON
LARIMER
WELD
LOGAN
SEDG-WICK
PHILLIPS
MORGAN
YUMA
RIO BLANCO
GRAND
BOULDER
GILPIN
ADAMS
WASHINGTON
GARFIELD
EAGLE
CLEAR CREEK
DENVER
ARAPAHOE
SUMMIT
JEFFER-SON
ELBERT
KIT CARSON
MESA
PITKIN
LAKE
PARK
DOUGLAS
LINCOLN
DELTA
GUNNISON
CHAFFEE
TELLER
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ARCHULETA
CONEJOS
COSTILLA
LAS ANIMAS
BACA
JULESBURG
CRAIG
STEAMBOAT SPRINGS
WALDEN
FORT COLLINS
GREELEY
STERLING
HOLYOKE
FORT MORGAN
AKRON
WRAY
MEEKER
BOULDER
GOLDEN
GLENWOOD SPRINGS
CASTLE ROCK
LEADVILLE
GRAND JUNCTION
BUENA VISTA
COLORADO SPRINGS
DELTA
GUNNISON
SALIDA
MONTROSE
CANON CITY
PUEBLO
SAGUACHE
LAMAR
LA JUNTA
WALSENBURG
MONTE VISTA
ALAMOSA
SPRINGFIELD
DURANGO
TRINIDAD
CONEJOS
Clay Treated Canal
Clay Treated Pond
Favorable Clay Deposit
Unfavorable Clay Deposit
Miles
0 5 10 15 20 25

TABLE I(a)

SUMMARY OF LABORATORY EVALUATIONS OF COLORADO CLAYS GIVING FAVORABLE RESULTS

Sample No.	Name and Location	Tested in 1961	Colloidal Yield %	Grit Content %	Filter Perm. ml/min	Layer Perm. ft/day	Mixability Index %	Swell Index %	Cation Exchange Capacity meg/100 g.	Exchangeable Sodium Percentage	X-Ray Diffraction Analyses
					Arkansas River Drainage Basin						
S48-1	Mumma W of Salida		30.6	2.4	4.3	0.0003	89.7	110	82.1	27.3	Mostly montmorillonite, w/quartz & gypsum (2 water layer)
-2	"		18.4	21.4	3.0	0.0005	61.5	45			
S49-1	Lamberg SE of Salida		15.9	37.5	3.4	0.001	73.3	35			
-2	"		17.6	57.2	2.7	0.001	21.6	20			
-3	"		35.6	6.7	2.5	0.0003	77.7	100	101.1	23.8	Practically pure montmorillonite, some Feldspar
-4	"		49.8	22.1	1.9	0.0003	54.3	75			
-5	"	x	30.2	15.0	2.9	0.0009	83.3	105			
-6	"	x	34.3	18.8	4.4	0.001	96.5	200			
-7	"	x	26.4	34.5	3.0	0.002	62.4	90			
-8	"	x	21.6	9.2	2.9	0.001	81.3	95	103.8	23.8	*
-9	"	x	20.4	9.7	2.7	0.001	77.6	110			
S34-1	Kessler Near Howard		26.1	0.9	26.7	0.0	93.5	60	103.1	8.4	*
-5	"		27.7	2.6	10.1	0.001	97.5	50			
S64-3	Harvey Bros. Near Parkdale		23.9	8.3	8.5	0.003	11.0	-10			
S28-1	Dilley N of Canon City		39.5	8.3	5.1	0.0006	77.5	98			
-2	"		39.6	7.9	4.8	0.002	34.9	88	40.2	25.9	Mostly montmorillonite & calcite, w/quartz & plagioclase
-3	"		37.0	9.1	10.3	0.0006	48.5	90			
-4	"		49.3	2.0	7.7	0.003	--	30			
-5	"		30.2	5.8	8.3	0.007	--	60			
-6	"		43.8	6.0	8.0	0.0	--	100			
-7	"	x	34.4	11.4	7.7	0.004	57.9	90	41.9	23.6	*
-8	"	x	31.3	11.7	8.9	0.004	63.9	70			
-9	"	x	33.9	8.8	5.5	0.005	51.3	50			
-10	"	x	37.1	9.6	4.7	0.008	85.0	60			
-11	"	x	35.8	8.8	4.0	0.006	98.2	5			
-12	"	x	34.1	8.5	4.7	0.009	96.0	40			
-13	"	x	42.8	5.2	5.7	0.003	93.9	75			
S87-1	Sponholtz NW of Wetmore	x	31.0	4.8	25.6	0.006	61.3	90			
S82-1	Adkins NW of Penrose	x	20.8	42.7	4.1	0.0003	97.3	10			
S46-1	McAlpin Near Red Wing		39.7	25.0	1.6	0.0	12.2	90			
S44-1	Rodgers S of Las Animas		55.3	5.7	0.9	0.0	12.6	230			
-2	"		63.0	4.1	0.9	0.0	11.5	312			
-3	Stough S of Las Animas		55.0	7.8	4.7	0.001	31.5	111			
-4	School Land S of Las Animas		66.1	1.9	3.6	0.0007	8.5	253	50.0	48.2	Sodium montmorillonite, ± 25% quartz, some Feldspar
-5	"		58.0	3.9	1.0	0.0	16.9	150			
-9	Butterfield S of Las Animas	x	59.5	0.8	1.6	0.001	19.1	--			
-10	"	x	39.6	6.7	1.9	0.0	19.6	--			
-11	"	x	30.3	23.9	10.0	0.001	42.6	--			
-12	"	x	59.9	0.8	1.9	0.0003	41.1	--			
-13	"	x	40.4	6.8	1.3	0.0	7.1	--			
S45-1	Wagner Near Las Animas		55.6	7.9	16.8	0.0005	38.2	130	87.5	12.1	Mostly gypsum, montmorillonite, w/kaolinite & quartz

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

*Testing underway but not completed

TABLE I(b)

SUMMARY OF LABORATORY EVALUATIONS OF COLORADO CLAYS GIVING FAVORABLE RESULTS

Sample No.	Name and Location	Tested in 1961	Colloidal Yield %	Grit Content %	Filter Perm. ml/min	Layer Perm. ft/day	Mixability Index %	Swell Index %	Cation Exchange Capacity meg/100 g.	Exchangeable Sodium Percentage	X-Ray Diffraction Analyses
					San Luis Valley						
S94-1	(?) N of Moffat	x	68.0	1.4	0.9	0.0	28.6	120			
S40-2	Chapman E of Hooper	x	42.8	6.3	1.1	0.0004	100.0	50			
S31-3	Wyble Near Creede		36.2	2.7	5.3	0.001	32.5	78			
					Colorado River Drainage Basin						
S21-3	Marshall Pass SE of Gunnison	x	16.4	39.7	2.9	0.0006	53.5	25	41.9	6.4	*
S43-1	Burton-Tuttle W of Aspen		36.0	7.0	17.1	0.009	46.9	55	15.0	3.3	*
S90-1	Granby Deposit Near Granby	x	31.9	9.4	1.1	0.0	18.3	120	43.5	37.7	*
-2	"	x	29.9	15.4	1.3	0.0	28.6	120			
S97-1	Foster NW of Bond	x	38.6	16.6	11.0	0.008	60.4	20	16.5	1.8	*
S75-1	Ball Near Meeker		26.0	8.6	2.8	0.0001	--	40			
-2	"		47.8	7.7	5.2	0.0002	--	35			
-3	"		11.6	3.8	3.3	0.0008	--	35			
S88-2	Wyman S of Maybell	x	36.8	6.2	1.4	0.0	29.1	300			
-3	"	x	39.1	11.6	6.1	0.0	21.7	220	42.1	18.3	*
-1	Preece S of Maybell	x	29.6	8.0	2.3	0.0	43.1	100			
-4	"	x	53.8	5.9	2.3	0.0007	37.6	115			
-5	"	x	20.6	6.4	4.2	0.0009	34.1	50	36.2	40.8	*
-6	"	x	16.7	20.7	4.7	0.0005	67.1	100			
-7	"	x	47.7	10.7	2.6	0.001	67.0	105			
-8	"	x	49.7	2.9	2.3	0.0004	56.1	125			
-9	Williams S of Maybell	x	62.3	3.2	1.8	0.0008	30.4	450	58.4	63.7	*CEC and % Na run on composite of S88-9 and 10
-10	"	x	51.5	18.3	1.6	0.0006	38.9	420			
S91-1	Stedtman E of Rangely	x	64.0	0.9	7.0	0.0006	45.9	120			
-2	"	x	36.8	5.8	2.9	0.0005	40.1	115	39.4	67.5	*
S84-1	Cornforth Near Olathe	x	43.5	7.9	6.9	0.002	29.5	230			
S72-1	Peach Valley E of Delta		60.8	7.3	10.0	0.001	46.1	132	57.9	37.0	Sodium montmorillonite, kaolinite, quartz w/Feldspar
S79-1	Rump W of Gr. Jctn.	x	46.5	6.5	1.9	0.0	20.9	190	65.4	59.3	*
-2	"	x	45.6	8.7	2.3	0.0	18.0	190			
S42-1	Rump W of Gr. Jctn.		47.2	9.4	1.5	0.0	14.7	171			
-2	Redlands W & P W of Gr. Jctn.		44.1	9.4	3.6	0.0009	37.5	120			
-3	"		31.1	10.6	3.4	0.0007	27.5	90			
-4	Grounds W of Gr. Jctn.	x	45.8	4.5	2.3	0.002	13.5	270	56.0	50.2	*
-5	"	x	33.5	2.1	2.1	0.001	11.9	175			
-6	Jacob's Ladder SW of Gr. Jctn.	x	52.4	4.0	1.0	0.0	0.9	700			
-7	"	x	70.5	3.0	1.2	0.0	7.1	800	75.2	60.2	*
					San Juan River Drainage Basin						
S101-1	Flora - W of Pleasant View	x	67.8	0.4	0.9	0.0	9.5	500			
-2	"	x	54.4	5.9	1.1	0.0	11.4	370			
-3	"	x	37.5	5.1	1.3	0.0	12.1	220			
-4	"	x	33.6	15.3	1.2	0.0	7.5	180			

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

*Testing underway but not completed

TABLE I(c)

SUMMARY OF LABORATORY EVALUATIONS OF COLORADO CLAYS GIVING FAVORABLE RESULTS

Sample No.	Name and Location	Tested in 1961	Colloidal Yield %	Grit Content %	Filter Perm. ml/min.	Layer Perm. ft/day	Mixability Index %	Swell Index %	Cation Exchange Capacity meg/100 g.	Exchangeable Sodium Percentage	X-Ray Diffraction Analyses
					South Platte River Drainage Basin						
S37-5	Marshall Lake N of Golden		50.0	1.8	23.7	0.003	68.7	50	34.0	2.1	Mixed layer montmorillonite, quartz, illite, kaolinite
S67-2	Bennett N of Golden		49.5	0.2	6.8	0.003	16.8	40	12.5	3.0	About 1/2 quartz, clay mainly kaolinite
S68-1	Lindsey N of Golden		33.4	2.8	5.3	0.006	66.7	30	12.2	1.3	Mostly quartz, balance kaolinite and illite
S62-1	Wisenhunt Near Castle Rock		52.4	2.1	11.2	0.004	12.6	40	19.9	2.7	Kaolinite, quartz & illite in approximately equal amounts
-2	"		43.1	5.3	8.9	0.003	10.9	20	9.5	2.6	Mostly quartz, kaolinite only other constituent
S31-1	Wyble N of Wellington		57.7	1.8	8.6	0.002	32.8	108	38.1	1.0	Mostly quartz, illite & kaolinite, some Feldspar
S33-1	Monroe N of Ft. Collins		73.3	3.1	189.0	0.009	82.7	143	78.3	1.0	Montmorillonite w/kaolinite, gypsum, plagioclase, calcite
-2	"		78.2	2.0	0.9	0.001	47.1	163	78.3	2.1	Similar to S33-1, perhaps more gypsum
S52-1	Warren N of Ft. Collins		61.0	3.7	78.0	0.007	82.9	60	49.5	0.9	Mostly montmorillonite, considerable quartz, w/Feldspar
S38-1	Norton NW of Ft. Collins		64.1	0.6	17.8	0.001	43.8	70			
-2	"		56.5	1.6	10.5	0.003	86.1	110			
S83-1	Roberts Ft. Collins (?)	x	23.5	23.4	5.4	0.001	46.3	35			
-2	"	x	22.7	27.9	3.4	0.0006	69.9	25			
S63-2	Cline Near Kiowa (?)	x	56.0	0.9	6.3	0.004	67.4	60			
-4	"	x	56.4	0.4	4.9	0.0009	10.2	120			
S36-2	Schrader N of Ft. Morgan		43.7	2.6	13.3	0.004	99.1	110			
-4	"		52.3	1.7	26.7	0.004	47.0	132	77.2	3.3	Mostly montmorillonite, w/quartz
-5	"		57.6	5.5	48.7	0.0009	77.9	99	50.6	6.3	Quartz, montmorillonite, illite, w/gypsum & Feldspar
S63-1	Last Chance SW of Akron		41.9	1.7	12.1	0.004	24.3	58	27.2	4.3	Quartz, w/montmorillonite, illite, Feldspar, gypsum
					North Platte River Drainage Basin						
S89-1	Colter E of Walden	x	56.7	5.7	6.2	0.005	14.7	290			
-2	"	x	72.2	1.0	4.0	0.0004	16.6	330			
-3	"	x	59.4	3.7	3.6	0.0	12.7	420			
-4	"	x	63.8	6.1	10.7	0.0006	17.9	180			
-5	"	x	69.6	2.0	4.1	0.002	10.0	300	87.0	34.6	*
-6	"	x	65.3	2.1	2.7	0.0	6.3	360			
-7	"	x	54.2	0.9	1.0	0.0	4.3	620			
					Commercial Bentonite						
S00-1	American Colloid Mississippi		58.6	5.8	35.9	0.01	--	110	67.4	65.5	*
S00-6	Benton Clay Wyoming		70.3	1.6	0.8	0.0	--	225	61.9	88.8	*
S00-5	Black Hills Bent. Wyoming		87.8	2.8	0.8	0.1	--	627	--	--	

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

*Testing underway but not completed

OUTLINE OF LABORATORY TESTING PROCEDURE

Sample Preparation--Upon being received in the laboratory, each sample is assigned a lab number, air-dried, and crushed to 3/4-inch or less size. A representative test portion is crushed to pass a U.S. No. 8 sieve (0.1-inch openings) and is oven-dried at 100°C. Most of the following tests are performed on this sample.

Colloidal Yield--This is the percentage (by weight) of sample that is extremely fine-grained or of colloidal clay size (no grittiness when tasted). It is determined by dispersing or mixing thoroughly 20 gms (0.7 oz.) of test sample with 1.5 gms of dispersant (sodium tripolyphosphate or calgon) in 1000 cc (1.06 qts) of distilled water. After being thoroughly dispersed, the mixture is allowed to set undisturbed for 24 hours. At the end of the settling period, the cloudy mixture remaining, is skimmed off and wasted and the sediment at the bottom of the jar is dried and weighed. The colloidal yield is obtained by difference and expressed as a percentage of the total weight of test sample.

Grit Content--This is the percentage (by weight) of sample that is of sand or larger size. The sample is prepared as for the colloidal yield test, but the clay-dispersant-water mixture is run through a U.S. No. 200 sieve (openings .074 mm or .003 in.) in place of the 24-hour settling procedure. The grit content is the percentage (by weight) of the total sample that is retained on the U.S. No. 200 sieve (wet).

Mixability Index--This test gives a relative idea of how easily the sample clay can be dispersed or mixed with water. It is obtained by subjecting a 20 gm sample of selectively sieved material (passing U.S. No. 4 and retained on U.S. No. 8 sieve) to a standard washing test. The result is expressed as a percentage of the original sample lost in a 30 second washing period.

Swell Index--This test determines the amount of swell that the sample will exhibit when wetted. It is performed on a selectively screened material (passing the U.S. No. 30 sieve and retained on the U.S. No. 50 sieve). It compares the wet volume of sample to the dry volume.

Cation Exchange Capacity--This test measures the chemical activity of the sample. It is a standard soils test. The results are expressed in milliequivalents per 100 gms of sample. This testing and that for the following test (Exchangeable Sodium Percentage) was performed by the CSU Agronomy Department (Soils).

Exchangeable Sodium Percentage--This test determines the percentage of sodium involved in the total cation exchange capacity previously described.

X-Ray Diffraction--This mineralogical determination on some of the samples was completed by the CSU Geology Department.

TABLE II

SUMMARY OF LABORATORY EVALUATIONS OF COLORADO CLAYS GIVING UNFAVORABLE RESULTS

Sample No.	Name and Location	Tested in 1961	Filter Perm. (ml/min)	Layer Perm. (ft/day)
	ARKANSAS RIVER DRAINAGE BASIN			
S29-1	Pachek Near Salida		24.8	--
S34-2	Kessler Near Howard		19.1	0.02
-3	" "		18.6	0.03
-4	" "		23.1	0.02
-6	" "		36.2	0.03
S47-1	Moss Near Westcliffe		18.0	0.20
S78-1	Vahldick Near Westcliffe		39.0	*
-2	" "		36.5	0.07
-3	" "	x	11.9	*
-4	" "	x	12.8	*
-5	" "	x	12.3	0.03
-6	" "	x	9.4	0.05
S64-1	Harvey W of Canon City		130.0	0.07
-2	" "		79.2	*
S32-1	Davidson N of Canon City		79.1	0.03
S87-2	Sponholtz NW of Wetmore	x	18.9	0.03
S86-1	Harmon Cripple Creek	x	6.1	0.03
S59-1	Wands Stone City		10.5	0.04
-2	" "		11.9	0.03
S73-1	Mahan Near Pueblo		9.8	0.04
-2	" "		17.0	0.03
-3	Everhart Near Pueblo	x	11.0	0.05
S35-1	Embry Near Pueblo		75.6	0.07
S60-1	Welte N of Colorado Springs		48.8	0.06
-2	" "		35.6	0.04
-3	" "		38.0	0.03
-4	" "		57.0	0.03
S44-6	Butterfield S of Las Animas	x	19.4	0.20
-7	" "	x	64.7	0.20
-8	" "	x	15.4	0.03
-14	John Martin Reservoir	x	12.7	0.03
	SAN LUIS VALLEY			
S30-1	Hopkins Near Center		10.8	0.06
S40-1	Chapman Near Center		36.2	0.03
S100-1	Trinchera Ranch SE of Ft. Garland	x	3.3	0.01
-2	" "	x	6.4	0.07
-3	" "	x	6.1	0.07
S93-1	Smith W of Mesita	x	6.4	0.02
-2	Braiden-Rivera SE of LaJara	x	26.0	0.50
-3	" "	x	25.2	0.70
	COLORADO RIVER DRAINAGE BASIN			
S21-2	Mealy Near Gunnison	x	18.1	0.07
S96-1	McNulty Near Carbondale	x	19.7	0.10
-2	" "	x	47.5	0.20
-3	" "	x	25.8	0.02
-4	Graves Near Aspen	x	6.4	0.03
S99-1	Calkins Near Steamboat Springs	x	17.5	0.03
S85-1	Beckett Near Craig	x	11.1	0.03
S75-4	Hwy 132 to Burford from Meeker	x	12.7	0.04
-5	" "	x	12.8	0.06
-6	Urruty E of Meeker	x	19.7	0.02
S91-3	Murdock E of Rangely	x	10.6	0.04
	SAN JUAN RIVER DRAINAGE BASIN			
S92-1	Walls Near Durango	x	191.0	*
-2	" "	x	37.9	*
	SOUTH PLATTE RIVER DRAINAGE BASIN			
S51-5	Smith E of Ft. Collins	x	100.5	*
S52-2	Green Acre N of Ft. Collins		30.5	0.03
-3	Warren N of Ft. Collins		185.0	*
-4	" "		159.0	0.02
-5	" "		200.0	0.05
-6	" "		145.1	*
-7	" "		18.4	*
-8	" "		194.0	*
-9	" "		32.3	0.04
-10	" "		97.3	*
	SOUTH PLATTE RIVER DRAINAGE BASIN (Cont'd)			
S52-11	Warren N of Ft. Collins		98.2	0.07
-12	" "		66.7	0.03
-13	" "		79.8	0.04
-14	" "		79.0	0.09
-15	" "		90.0	*
-16	" "		72.7	0.06
-17	" "		42.5	0.04
-18	" "		66.4	0.03
S31-2	Wyble Near Wellington		269.3	*
S33-3	Monroe N of Ft. Collins	x	30.0	*
S69-1	Harris Near LaPorte		11.5	0.03
S76-1	Buck Near Ft. Collins		*	*
S77-1	Schrader Near Rockport		42.2	0.04
-2	" "		35.0	0.03
S54-1	Brick Plant S of Ft. Collins		26.3	0.03
S41-1	Smith E of Ft. Collins		22.5	0.03
S51-1	" "		29.1	*
-2	" "	x	10.1	0.20
-3	" "	x	16.4	*
-4	" "	x	84.4	*
S53-1	White Rose Coal Mine Near Carr		78.6	0.04
-2	Lone Tree Creek Near Carr		39.2	0.06
S102-1	Watts Near Windsor	x	19.4	0.10
S80-1	Phipps Near Loveland	x	19.3	*
S55-1	Clover Basin Reservoir		36.0	0.02
S37-1	Rocky Flats N of Golden		25.6	0.07
-2	Strainland N of Golden		15.5	0.01
-3	Plainview N of Golden		15.9	0.02
-4	Rocky Flats N of Golden		20.2	0.01
-6	Marshall SE of Boulder	x	10.1	0.04
-7	" "	x	9.0	0.03
-8	" "	x	11.4	0.03
-9	" "	x	9.5	0.03
-11	" "	x	15.9	0.06
S39-1	Stanley Lake Near Arvada		36.1	0.05
-2	" "		18.1	0.02
S67-1	Bennett N of Golden		56.4	*
S50-1	Skinner N of Golden		56.0	*
S56-1	Lee Cox NE of Morrison		19.4	0.03
S66-1	Pallaoro Near Morrison		16.9	*
S61-1	Harris E of Castle Rock		32.2	*
S57-1	Robinson Near Peyton		39.8	*
S58-1	Robinson Near Calhan		12.6	*
-2	" "		12.5	*
S63-3	Cline Near Kiowa	x	4.4	0.06
S65-1	Harris W of Kiowa		17.6	*
S36-1	Schrader N of Ft. Morgan		28.9	0.02
-3	" "		17.9	0.01
-6	" "		55.7	0.07
-7	" "		77.2	0.10
-8	" "		97.5	0.08
S74-1	" "		74.6	0.02
-2	" "		74.6	0.02
-3	" "	x	111.3	*
-4	" "	x	31.0	*
-5	" "	x	119.1	*
-6	" "	x	12.0	0.10
-7	" "	x	35.5	*
-8	" "	x	118.0	*
-9	" "	x	117.0	*
-10	" "	x	52.8	*
S71-1	Hwy 63 N of Akron		19.5	0.06
S70-1	Yahn Near Iliff		54.4	*
-2	" "		38.0	*
-3	" "		94.0	*
-4	Baver Near Iliff		12.1	0.04
S95-1	Cottonwood Ranch W of Sedgwick	x	77.0	0.10

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

*Was not tested

OUTLINE OF LABORATORY TEST PROCEDURE (Cont'd)

Layer Permeability--The sealing efficiency of a loosely-placed (not compacted) layer of the sample clay is measured in this test. It is determined by measuring the rate of flow of distilled water through a sample layer of about 0.6 inches in thickness under a falling water level or head, starting at 52 inches of water depth. With the permeability rate (determined in the lab) and the expected water depth in the canal or pond, it is then possible to determine the thickness of clay layer required. For comparison, several typical values are tabulated below:

Permeability (ft/day)	Thickness* of clay (in inches) for water depth 1 ft	3 ft	5 ft	10 ft
.01	1.4"	4.3"	7.2"	14.4"
.001	0.1"**	0.4"	0.7"	1.4"
.0001	0.01"**	0.04"**	0.07"**	0.14"**

* For loss per 24 hours of 1-inch drop in water level.

**For low application thicknesses, other factors may become more important than these values--such as size of lumps in clay material or method of spreading clay.

Filter Permeability--This test measures the sealing ability of a mixture of the sample and water (without dispersant). It is accomplished by placing 400 ml (0.4 qt) of a 2.0% mixture of sample and distilled water (8 gms clay in 400 ml water) in a special pressure filter apparatus. The mixture is filtered through a standard filter paper under a head equal to 34 feet of water. The rate of loss of water is measured and expressed in ml/minute. As a comparison, note the loss rates for several common materials:

1/8-inch layer of No. 40 Ottawa sand lost 1440 ml/min
1/8-inch layer of local sandy soil lost 1003 ml/min
The filter paper alone lost 651 ml/min
Best clay samples have a loss rate below 10 ml/min.

TABLE III

SUMMARY OF RESULTS TO DATE FROM FIELD INSTALLATIONS IN EASTERN COLORADO WITH COLORADO CLAYS

Job Title Location	Capacity Grade	WP* L	Bed Material	Installation Date Amount of Bentonite	Method of Application	Total Cost	Benefits**
				ARKANSAS RIVER DRAINAGE BASIN			
Cottonwood Creek W of Buena Vista	60 cfs-July Variable	22 16000	Rocky-gravelly	July 1960 100 tons (S49)	Wash-in	$450	About 200 AF saved in 1960*
Arkansas Valley Irrigation Canal SW of Buena Vista	20 cfs Flat	8 1400	Rocky-gravelly	July 1961 14 tons (S49)	Multiple-dam	$130	Before loss = 22% } measured After loss = 17% } w/flumes
Bray Ditch - Irwin W of Buena Vista	10 cfs Steep	4 11000	Rocky	July 1960 20 tons (S49)	Wash-in	$180	Water saved in 1960 produced hay worth $1000
W Gate and S Meadow Diversion SW of Buena Vista	8 cfs Steep	4 13000	Rocky	June 1960 28 tons (S49)	Multiple-dam	$250	Water saved in 1960 produced hay worth $800
Lee Diversion Ditch SW of Buena Vista	4 cfs Steep	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 Steep	3 16000	Rocky	June 1961 25 tons (S49)	Wash-in	$225	Water saved produced hay worth $400
Sailor Seep Ditch SW of Buena Vista	4 cfs Steep	3 3500	Rocky	Sept. 1960 24 tons (S49)	Multiple-dam	$215	Value of water saved first year equal to cost of bentonite
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.)
Bray Ditch W of Buena Vista	10 cfs Steep	4 4000	Rocky	April 1960 4 tons (S49)	Wash-in	$40	Water saved in 1960 produced hay worth $100
Dry Creek Diversion Ditch SW of Buena Vista	2 cfs Steep	2 8000	Rocky	June 1960 20 tons (S49)	Wash-in	$180	Treatment brought flow 3/4 mile farther in ditch
Pioneer Ditch SW of Nathrop	10 cfs Steep	4 4000	Rocky	May 1960 42 tons (S49)	Comb. wash-in and multiple-dam	$380	Water saved in 1960 produced hay worth $1600
Missouri Park Ditch NW of Salida	70 cfs Medium	10 37000	Rocky-gravelly	1959-1961 234 tons (S49)	Multiple-dam	$160	Cut seep loss at least 75% Before loss--8 of 10 cfs
North Fork Ditch W of Salida	22 cfs Medium	10 5300	Gravel/sand and silt	April 1961 30 tons (S49)	Multiple-dam	$180	Water saved in 1961 produced hay worth $1000
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: 4 cfs loss in 1/4 mi.(meas.) After: 1 cfs loss in 4 mi. (meas.)
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
Branch of 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
Boyle Pond NW of Salida	1/2 AF - -	- - - -	Sand and gravel	1957-1959 1/2 ton (S49)	Membrane	$10 (est.)	Before: 50% loss overnight After: practically no loss
Tenderfoot Stock Pond N of Salida	- - - -	- - - -	Peat	Fall 1959 2 tons (S49)	Membrane	$30 (est.)	Bentoniting produced enough new water for 50 head of cattle
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: no longer used
Adamson Pond SE of Howard	5 AF - -	- - - -	Cobbles-gravel	April 1960 80 tons (S34)	Membrane	$450 (est.)	Before: new pond After: 1 foot drop/24 hrs.
Goodwin Pond SE of Howard	8 AF - -	- - - -	Rocky-gravelly	April 1960 160 tons (S34)	Membrane	$700 (est.)	Before: 1-1/2 foot drop/24 hrs. After: 1-1/2 foot drop/mo.
Hogback Ditch NW of Westcliffe	5 cfs Steep	5 16000	Rocky	Fall 1960 112 tons (S49)	Wash-in	$1120 (est.)	Water saved in 1960 produced hay worth $1000
Garden Park Ditch N of Canon City	9 cfs Steep	4 4000	Rocky-sandy	May 1960 32 tons (S28)	Wash-in	$160 (est.)	Before: 30% loss (est.) After: 10% loss (est.)
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 and multiple-dam	$500 (est.)	Seep areas dried up below ditch, est. 20% more water after bentoniting
Red Rock Ranch Ponds W of Monument	3-10 AF 4 ponds	- - - -	Sandy and gravelly	Early 1959 and 60 10 tons (S49)	Membrane	$600	Before: would not hold water After: holds very well
Meserow Pond No. 1 Near Colorado Springs	30' Dia. - -	- - - -	- -	Spring 1960 7 tons (S49)	Membrane	$90	Before loss: 12-inch/day WL drop After loss: 1/2 inch/day WL drop
Meserow Pond No. 2 Near Colorado Springs	30' Dia. - -	- - - -	- - - -	Fall 1960 4 tons (S49)	Membrane	$60	Before loss: 12-inch/day WL drop After loss: 1/2 inch/day WL drop
Fountain Mutual Ditch SE of Colorado Springs	8 cfs Medium	4 15000	Sandy loam	July 60 and May 61 75 tons (S28)	Wash-in	$750	Approx. 60 AF of water saved in 1961 worth about $360
Security Village Sewage Lagoons SW of Security Village	2 (acres) - -	- - - -	Sand and gravel	Summer 1959 600 tons (S28)	Membrane	$6000	Was lined during construction--holding satisfactorily
				SOUTH PLATTE RIVER DRAINAGE BASIN			
Circle Farm Pond E of Fort Collins	8 AF - -	- - - -	Gravel, some clay	Oct. 1960 120 tons (S33)	Membrane	$600	Before: 3' drop in 3 days After: 4' drop in 5 days
MacIntyre Ditch E of Berthoud	8 cfs Variable	5 10000	Sandy to 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	Shale, limestone and gravelly clay	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 back-fill
Wellington Lake Feeder Canal SE of Baily	40 cfs Medium	13 3000	Decomposed granite	July 1960 36 tons (S49)	Multiple-dam	$750	Est. $2600 of water saved during 1961 (520 AF)
W. Burlington Ext. Canal NE of Denver	35 cfs Flat	12 50000	Sandy	Sept. 1960 52 tons (S37)	Wash-in	$150	Some reduction in seepage but not measured
				REPUBLICAN RIVER BASIN			
Wray Hatchery Ponds Wray	2 AF - -	- - - -	Sandy	Summer 1961 160 tons (S44)	Membrane	$1800 (est.)	Holding well

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TABLE IV

SUMMARY OF RESULTS TO DATE FROM FIELD INSTALLATIONS IN WESTERN COLORADO WITH COLORADO CLAYS

Job Title Location	Capacity Grade	WP* L	Bed Material	Installation Date Amount of Bentonite	Method of Application	Total Cost	Benefits**
RIO GRANDE RIVER DRAINAGE BASIN (SAN LUIS VALLEY)							
Shewalter Pond S of Poncha Pass	6-1/2 AF - -	- - - -	Gravel-shale, peat	1959-60 123 tons (S49)	Membrane	$1100	Before: 50% loss/day (est.) After: majority of seep stopped
Dominick Ranch (Creek) E of Villa Grove	- - Steep	- - 5300	Rocky	1960 8 tons (S49)	Wash-in	$90 (est.)	Water saved in 1960 produced hay worth $1500
Steele Creek SE of Villa Grove	- - Steep	- - 8000	Rocky	June 1960 20 tons (S49)	Wash-in	$250 (est.)	Water saved in 1960 produced hay worth $1500
Cotton Creek Ditch SE of Villa Grove	15 cfs Steep	8 17500	Cobbles-gravel	July 1961 210 tons (S49)	Wash-in	$3000 (est.)	Saved about 1000 AF during 1961 irrigating season
O'Brien Ditch SE of Villa Grove	10 cfs Variable	6 19000	Sandy-gravelly	Nov. 1959 136 tons (S49)	Multiple-dam	$1670	Before: 4 cfs loss/1/4 mi. After: 3 cfs loss/3-1/2 mi.
Shellabarger Ditch SE of Villa Grove	10 cfs Steep	6 11000	Sandy-gravelly	1959-60 50 tons (S49)	Multiple-dam	$600	Before: 3 cfs loss/2 mi. After: 1 cfs loss/2 mi.
Brace Pond No. 1 and No. 2 N of Center	10 and 12 AF - -	- - - -	Sandy-gravelly	Jan. 60, Jan. 56 1500 tons (loc.)	Membrane	$3000	Total benefits for ponds--$1500/yr.
Coors Farm Pump No. 3 Ditch N of Center	6 cfs Flat	7 1320	Sand and gravel	Aug. 1959 12 ton (S49)	Multiple-dam w/ditcher	$200	Dried-up seep in road
Hooper School Skate Pond SE of Hooper	1/3 AF - -	- - - -	Sandy-loam	1959-1960 30 tons (S49)	Membrane	$250 (est.)	Before: 100% loss in 10 hrs. After: practically no loss
Mosca School Skate Pond W of Mosca	1/2 AF - -	- - - -	Sandy-loam	Oct. 59, Sept. 60 70 tons (S49+loc.)	Membrane	$300 (est.)	Recreational value $250/yr.
Benson Ditch NE of Del Norte	3 cfs Medium	4 1500	Rocky	Aug. 1960 13 tons (S49)	Multiple-dam	$200	Saves about 90 AF/yr., worth about $300/yr
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/yr.
Quinlan Pond Antonito	- - - -	- - - -	Silty clay	Aug. 1961 6 tons (S49)	Membrane	$40	Water produced due to bentoniting --$100/yr
Trinchera Ranch Ditch SE of Fort Garland	9 cfs 5000	6 5300	Sand and gravel	July 1956 8 tons (S49)	Multiple-dam	$100 (est.)	Before: 1/2 cfs loss in 1 mi. After: 1/5 cfs loss in 1 mi.
COLORADO RIVER BASIN							
Chittington Highline Ditch NE of Parlin	32 cfs Medium	9 3000	Rocky-sandy	Oct. 1959 37 tons (S49)	Multiple-dam	$650 (est.)	Dried up seep areas in meadow-produced $300/yr. (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
Dunbar Ranch Ditch NE of Almont	5 cfs Medium	2 4000	Open fractured rock-silt	May 1961 7 tons (S49)	Multiple-dam	$150	Held for approx. 3 weeks and seepage resumed.
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
Twin Lakes West Slope System SE of Aspen	20-350 cfs Medium	10-28 20000	Fractured rock and talus	Sum. 56,57 - 300 t (S49) 500 t (Wyo.)	Multiple-dam	$20,000	Before loss: 100% at low flows After loss: 25% at low flows
Climax Canal No. 1 NE of Climax	100 cfs Medium	9 5700	Rocky	1960 91 tons (S49)	Multiple-dam	$1140	Noticeable water saving, but no measurements made
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
Farmers Irrig. Co. Sub. Lateral 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 1961
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 in nearby house
1st lift ditch W of Grand Junction	35 cfs Medium	25 550	Fractured shale and silt	Dec. 1960 110 tons (S42)	Membrane	$830	Dried-up seep area blocking garage of nearby house
2nd lift ditch W. of Grand Junction	13 cfs Flat	11 2600	Sandy silt	Mar. 1960 40 tons (S42)	Membrane	$400 (est.)	Good initial seal but did not last--erosion cut membrane
Rump Ranch Ditch Near Bridgeport	4 cfs Flat	4 400	Sandy silt	June 1960 10 tons (S42)	Membrane	$100 (est.)	Holding well
Marshall Nay Ditch SW of Toponas	4 cfs	4 600	Sand	June 1961 1/2 ton (S42)	Multiple-dam	$20 (est.)	Initial seal good
Hank 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
SAN JUAN RIVER BASIN							
Nanniga Stock Pond Pagosa Springs	0.1 AF - -	- - - -	Gravel, some clay	Aug. 1960 5 tons (S49)	Membrane	$125	Before: would not hold water After: holds very well
Hayden Pond N of Pagosa Springs	1.5 AF - -	- - - -	Soil and shale	Spring 1960 1 ton (S49)	Membrane Wash-in	$30	Value of water saved--$100/yr.
Smith Pond Pagosa Springs	0.5 AF - -	- - - -	Decomposed shale	Spring 1960 3 tons (S49)	Membrane	$100	Partial seal only
Lynn Stock Pond Pagosa Springs	1 AF - -	- - - -	Rocky and gravelly some clay	July 1960 10 tons (S49)	Membrane	$200	Value of water saved--$500/yr.
Olson Stock Pond W of Pagosa Springs	0.5 AF - -	- - - -	Soil and shale	July 1960 1 ton (S49)	Membrane	$25	Bentonite 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

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TABLE V

SUMMARY OF RESULTS TO DATE FROM FIELD INSTALLATIONS IN COLORADO WITH WYOMING BENTONITES

Job Title Location	Capacity Grade	WP* L	Bed Material	Installation Date Amount of Bentonite	Method of Application	Total Cost	Benefits**
WYOMING BENTONITE USED							
Coors Farm--Pump No. 4 Ditch N of Center	6 cfs Flat	7 2600	Sandy-gravelly	May 1956 6 tons (Wyo.)	Jet-mixer plus ponding	$200	Seepage losses reduced 70%. Est. value of water saved--$560
H-1 Pond S of Fort Garland	4 AF - -	- - - -	Gravel, sandy loam	April 1961 7 tons (Wyo.)	Membrane	$350	Save $6/day pumping cost during irrigation season
R-2 Pond S of Fort Garland	5 AF - -	- - - -	Gravel, sand loam	April 1961 13 tons (Wyo.)	Membrane	$650	Save $6/day pumping cost during irrigation season
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 dried up
Hohnholtz Ditch W of Fort Collins	5 cfs Medium	12 200	Gravel and sand	Summer 1959 7 tons (Wyo.)	Multiple-dam	- -	Holding well (1961)
Weaver Ranch Ditch NW of Fort Collins	2 cfs Variable	5 1000	Rocky, sand and silt	June 1956 2/3 tons (Wyo.)	Jet-mixer plus ponding	$65	Cut losses in half (1956). Ditch not used now (1961)
N. Poudre No. 3 Lateral SW of Wellington	6 cfs Medium	8 9250	Sandy clay	Sept. 1955 4 tons (Wyo.)	Jet-mixer plus ponding	$125	Saved 1/2 AF/day (meas. 1956). No seal left in 1961
N. Poudre No. 4 Lateral SW of Wellington	3 cfs Flat	5 5300	Sandy w/clay layers	1954-1955 10 tons (Wyo.)	Jet-mixer plus ponding	$300	Saved 120 AF/1955 season (meas.). No seal left in 1961
Little Cache Ditch N. of Fort Collins	3 cfs Flat	5 6600	Sandy silty clay	Fall 1954 2 tons (Wyo.)	Jet-mixer plus ponding	$60	Saved 60 AF/1955 season. Ditch cleaning destroyed seal in 1958.
Farmers Irrigation Ditch E of Loveland	30 cfs Flat	20 2600	Silty clay	May 1956 3-3/4 tons (Wyo.)	Jet-mixer plus ponding	$150	Saved 126 AF in 1956 (meas.). Seal mostly gone in 1961
Christian Lateral E. of Campion	3 cfs Flat	5 2600	Silty clay	June 1956 2 tons (Wyo.)	Jet-mixer plus ponding	$95	Saved 14 AF in 1956 (meas.). Seal mostly gone in 1961
Sand Hill Reservoir NW of Fort Lupton	Dike - -	- - - -	Sandy	1957 100 tons (Wyo.)	Membrane	$3100	Extensive seep area below dam dried up
Wanamaker Ditch E of Golden	25 cfs Steep	6 700	Cobbles and gravel	Summer 1960 4 tons (Wyo.)	Membrane	$200	Reduced seepage loss appreciably (1960)
Zimbelman Farm Ditch SW of Keensburg	3 cfs Steep	4 2600	Sandy	July 1956 1-1/2 tons (Wyo.)	Jet-mixer plus ponding	$95	21 AF saved during 1956 (meas.). Seal lost during storm wash-out
Bijou Land Company Ditch W of Fort Morgan	5 cfs Steep	4 2100	Sandy	April 1956 2 tons (Wyo.)	Jet-mixer plus ponding	$125	Seal did not last due to erosion
Miller Farm Ditch NW of Atwood	2 cfs Flat	5 1000	Sandy	Summer 1956 3 tons (Wyo.)	Jet-mixer plus ponding	$185	42 AF saved during 1956 (meas.)

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