REPORT OF
SEDIMENT LINING INVESTIGATIONS
FISCAL YEARS 1954-55

By

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June 1955

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Civil Engineering Department
Colorado A and M College
Fort Collins, Colorado

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by
R. D. Dirmeyer, Jr.

with
Sub-sections by

G. E. Johnson,
The Central Nebraska Public Power and Irrigation District
B. N. Rolfe, U. S. Geological Survey
and
D. F. Peterson and R. B. Curry,
E. W. Lane and I. S. Dunn

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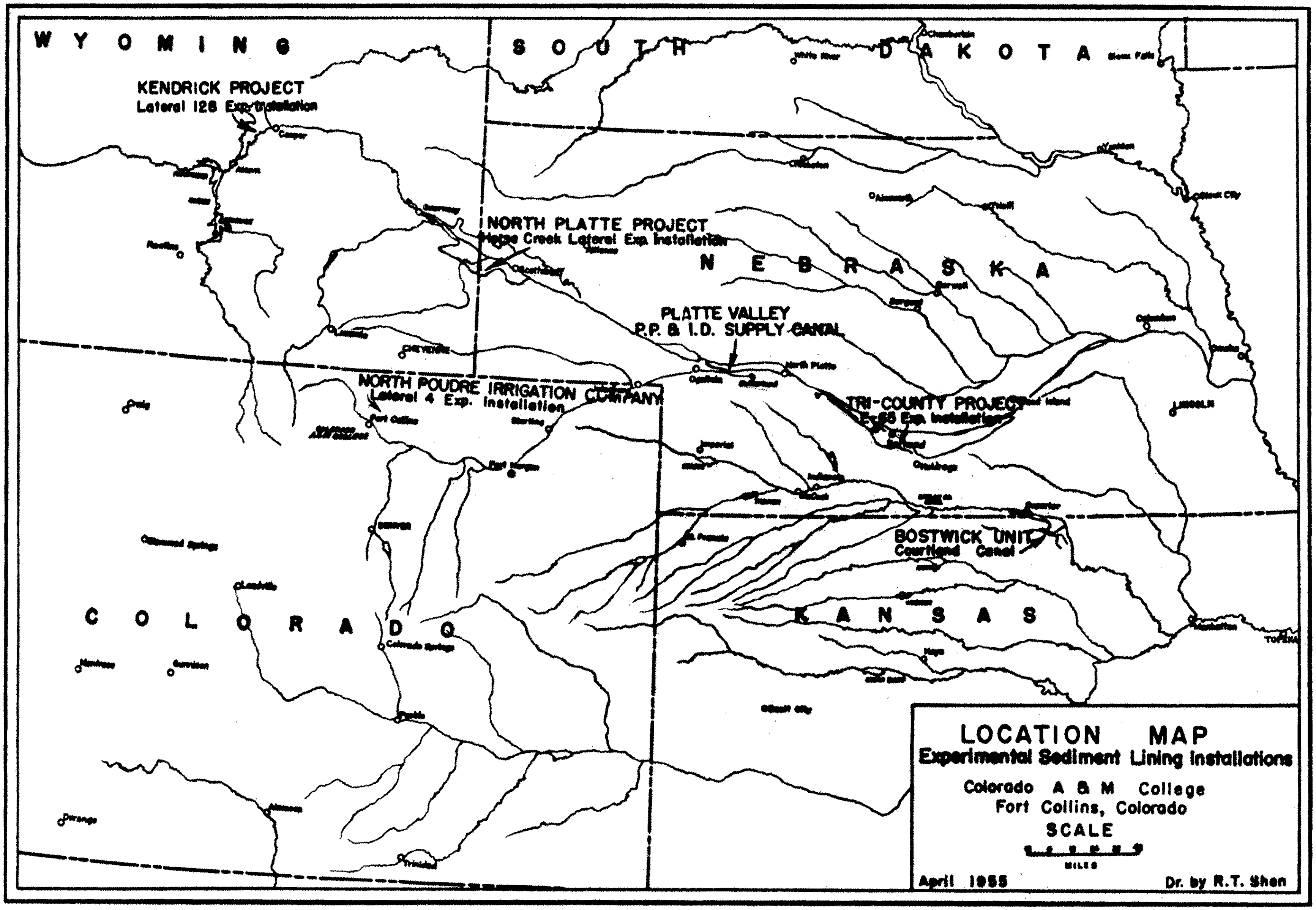
WYOMING
SOUTH DAKOTA
NEBRASKA
COLORADO
KANSAS
KENDRICK PROJECT
Lateral 128 Exp. Installation
NORTH PLATTE PROJECT
Horse Creek Lateral Exp. Installation
PLATTE VALLEY
P.P. & I.D. SUPPLY CANAL
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LOCATION MAP
Experimental Sediment Lining Installations
Colorado A & M College
Fort Collins, Colorado
SCALE
MILES
April 1955
Dr. by R.T. Shen

ACKNOWLEDGEMENTS

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The initial sediment lining work at the Bureau of Reclamation office at Casper, Wyoming, was conducted under the general supervision of I. J. Matthews, District Manager, and M. M. Starr, District Engineer. The author gratefully acknowledges their support and encouragement in the initial and the subsequent cooperative project work.

In the cooperative project work the Technical Advisory Committee has been a most helpful group in providing guidance. In addition to the College faculty members previously mentioned, N. A. Evans, Assistant Professor of Civil Engineering, has served on the committee and has contributed generously of his time. The following Bureau of Reclamation employees, who have served on the committee at one time or another, have been helpful: I. B. Hosig and P. W. Terrell, Canals Branch; R. J. Willson and Hollis Sanford, Irrigation Operations Branch; C. W. Jones and T. V. Woodford, Engineering Laboratories; and F. M. Roush, J. T. Maletic, H. E. Prater, and E. T. Bradford, Region VII office. In addition to those mentioned above, many other college staff members and federal employees have contributed to the work. To those directly or indirectly referred to above, the author expresses sincere thanks for the valuable help contributed during the experimentation and many suggestions regarding the preparation of this report.

In the college research phase of the sediment lining work, B. N. Rolfe of the U. S. Geological Survey has been a mainstay contributor. He has also provided very helpful assistance to important phases of the research work being conducted by R. B. Curry and Clive Newman, Graduate Fellows. In addition to the above, the valuable contributions of E. W. Lane, I. S. Dunn, and others, who have assisted the college phases of the sediment lining research, are gratefully acknowledged.

In the field installation phase of the cooperative work, it has been a pleasure working with the many irrigation district and Bureau men involved. The unusually significant contributions made by George E. Johnson and his Tri-County (C.N.P.P. and I.D.) organizations, by W. K. Lundgreen of the Bureau of Reclamation and by the several other irrigation districts are herein acknowledged. The ingenuity displayed by them in making their respective installations and the initial results obtained have been most valuable in the initial development of the sediment lining method.

The financial and/or technical information contributions of the following organizations have been a significant factor in the sediment lining work and especially in making it possible to initiate the fundamental research program at Colorado A and M College:

1. Irrigation organizations

   a. The Central Nebraska Public Power and Irrigation District, Hastings, Nebraska.

   b. Platte Valley Public Power and Irrigation District, North Platte, Nebraska

   c. North Poudre Irrigation Company, Fort Collins, Colorado.

   d. Gering and Ft. Laramie Irrigation District, Gering, Nebraska.

   e. Shell Irrigation Company, Greybull, Wyoming.

2. Bentonite producers

   a. American Colloid Company, Chicago, Illinois.

   b. Baroid Sales Division of National Lead Company, Houston, Texas.

   c. Benton Clay Company, Casper, Wyoming.

   d. Black Hills Bentonite Company, Moorcroft, Wyoming.

   e. Magnet Cove Barium Corporation, Houston, Texas.

   f. Royal Earth Company, Denver, Colorado.

   g. Wyotana Sales Company, Houston, Texas.

3. Chemical Companies

   a. Calgon, Inc., Pittsburgh, Pennsylvania.

   b. Victor Chemical Works, Chicago, Illinois

4. Mixing Equipment Companies

a. Cronese Products, Inc., Tarzana, California.

b. Mixing Equipment Company, Rochester, New York. (equipment loan)

Because of the large number of project cooperators this report has been reviewed by an equally large number of people. While it is not possible to acknowledge the contributions of each reviewer, the author does express a sincere appreciation for the valuable comments and suggestions thus received. Appreciation is expressed to R. T. Shen, who prepared most of the drawings and edited the manuscript.

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Chapter I

ADVANCE SUMMARY

The present cooperative sediment lining project was organized at Colorado A and M College (Civil Engineering Department) in July of 1953 as result of a contract with the Bureau of Reclamation. In this contract it was recognized that since the loss of water from irrigation systems prevents full, beneficial use of waters and often causes damage to irrigated lands, an urgent need exists for a low cost method of seepage control in canals and reservoirs. Since sediment linings offer promise of fulfilling this need for an effective and low-cost method of lining, it was mutually agreed by contract that a coordinated College and Bureau effort be initiated for the purpose of developing a dependable and effective sediment lining method. The contract was subsequently extended to cover fiscal year 1955 operations and it is believed that it will be extended again to cover fiscal year 1956 operations.

The contracts with the Bureau include provisions for admitting other cooperators in the research and development work on the sediment lining method. Additional cooperators now include: The Central Nebraska Public Power and Irrigation District and five other irrigation districts; the U. S. Geological Survey; six bentonite companies; one chemical company; and two mixing companies.

The objective of this report is to summarize the initial results of the first two years' activities of the cooperative sediment lining project at Colorado A and M College. The cooperative work with the Bureau of Reclamation is of primary interest, but the work with the other cooperators is also summarized. Much of the detail of the previous progress (College) and Bureau laboratory reports has been omitted.

It will be realized that in some instances the evaluation and research work is not yet complete. It is expected that subsequent yearly or individual reports will be prepared to cover each completed phase of fundamental and applied research work.

Sediment Lining Method

A large portion of the costs of most canal lining methods is incurred by (1) preparing the canal sub-grade, and (2) hauling and placing the lining material. Sediment lining is a method in which these costs can be materially reduced or eliminated by utilizing flowing canal water for transporting and placing the sealing material in only the leaky areas. These possibilities have motivated the cooperative research and development work in sediment lining.

The method is best described as a low-pressure injection or grouting procedure wherein a controlled charge of water and suspended sediment flowing down the leaky canal does the penetration sealing. The flowing water provides a stand-by reservoir of sealing material and at the same time supplies the pressure head causing the infiltration. The selective action occurs because of the seepage of the sedimenting water into only the leaky areas of the canal. It can occur only if the sedimenting material remains stably dispersed, for otherwise the sediment would settle out as a surface layer, which can be easily damaged. Under this selective infiltration action the lining material is concentrated in the cracks and voids where the major loss of water occurs. In canal bed areas where there is little or no loss there is virtually no lining action.

There are considerable precedents in nature for the sedimenting method: (1) pervious materials have been sealed and cemented by geological processes involving the seepage injection of water-borne sediments, and (2) the natural silting of irrigation canals by muddy waters is as old as irrigation. While the latter process suggested the sediment lining method there are significant differences. Silting, which usually involves the settling out of suspended materials by gravity, normally deposits a layer more or less uniformly over the canal bed regardless of whether the bed is leaky or not. In addition, this material usually does not penetrate the leaky zones and consequently is readily destroyed by erosion or drying. A major objective of the sediment lining method is to achieve penetration of the suspended material into the voids of the pervious materials of the canal beds. Of the natural materials that have infiltrated and sealed permeable materials, colloidal clays seem to be the most practical and available.

Advantages of Sedimenting Method -- For conventional lining methods, accurate location of the leaky zones in the canal bed is desirable since these are the ones to be lined. The expense of this work can be largely avoided in the sedimenting method because of its selective nature. The only equipment necessary is for canal cleaning, if needed, prior to the sedimenting, and for mixing or dispersing the sediment at the head end of the canal section being treated. The normal excavation and placement costs associated with most canal lining installations are almost entirely eliminated. The method is fast. An entire canal system can be treated in a relatively short period probably not exceeding a few weeks. Costs are accordingly very low because most of the work consists of a water running operation accomplished by regular irrigation crews. It is expected that if and when the demand develops, the services of experienced mixing contractors will be available for the larger installations.

Research Objectives and Methods

The general research objective of the cooperative sediment lining project work is to determine methods and materials to be used in the sediment lining of canals. A coordinated and integrated laboratory and field investigations approach is being utilized.

In general there seem to be four main variables in the sedimenting method: (1) sedimenting material, (2) irrigation water, (3) pervious canal bed material, and (4) canal operating conditions. In the initial cooperative work the sedimenting variable has been restricted to one class of clay materials -- high-swell bentonites. They were selected because of their colloidal characteristics, general availability and low-cost, and because methods have already been developed for dispersing them in water by the oil well drilling industry. The other variables were restricted by working on specific seepage problems in three major pervious soil types: loess, dune sand, and fractured rock. These pervious materials are causing major seepage problems on irrigation projects in the four-state area of Colorado, Wyoming, Nebraska, and Kansas. It is believed that they cause similar problems in other areas where irrigation is practiced. The initial work has been restricted to use in laterals that operate more or less continuously during the normal irrigation season. It has been assumed that a low-flow, full-ponding method of sedimenting could be used in the three major experimental installations. Under these conditions of sedimenting and of normal canal operation, a stably dispersed sedimenting mixture is a necessity.

Even under restricted conditions, major problems remain. These include development of operating and installation procedures, and understanding and controlling the side effects of bentonite sediment linings. The types of materials where high-swell bentonites may be effectively used need to be delineated and procedures for evaluating the effect of treatment developed and perfected.

Where possible, the preliminary development work--such as the dispersion testing involving site water and bentonite--has been performed in the laboratory. Field application, however, involves many important variables that cannot be readily duplicated in the laboratory. These include existing soil structure, natural sediment cakes, crayfish holes, depth to water table, salt status of soils and ground water, and canal operating conditions. On large systems wide variations of these factors may exist in various parts of the system. Thus, much of the preliminary testing has become an integral part of the initial field installation work. By restricting the initial installation work to small sections of laterals, which are a small representative part of their respective over-all canal systems, these canal variables have been economically taken into account.

Field Installations

Most of the cooperative research and development work has been conducted at three main experimental sites. Two experimental installations were made by the Bureau of Reclamation: (1) Kendrick Project installation in lateral 128; and (2) North Platte Project installation in a section of the Horse Creek lateral. The third major installation was made by The Central Nebraska Public Power and Irrigation District: Tri-County installation in a section of their E-65 main lateral system. The results are summarized in the order of installation work at the field sites.

Tri-County Installation in Loess Materials -- The entire E-65 system of the Tri-County Project traverses loessial materials exclusively. In the experimental installation in this area the lateral conditions before sedimenting, bentonite mixing, and sediment ponding procedures were favorable. The losses, as determined by ponding tests, were reduced from about 1 cubic foot per square foot per day to about 0.2 cubic foot per square foot per day. The losses are calculated on a water surface area basis. It is estimated that 5300 acre-feet of irrigation water was saved by the sediment lining during the 1954 irrigation season. This, according to project estimates, is worth to the water user about $79,500 as compared to the experimental costs of $15,000. The costs of lining was about 7 cents per square yard or about $1200.00 per mile of lateral. The average wetted perimeter is about 30 feet.

North Platte Installation in Dune Sand Materials -- In this installation the intermittent lateral reaches in dune sand are of foremost interest, but some sealing was also obtained in fractured siltstone, and sandy to silty slopewash. In this experimental installation the presedimenting conditions of lateral, bentonite mixing, and sediment ponding procedures were not entirely satisfactory. Before and after ponding tests were not run so no estimate of water saved can be made. Seeped land below the lateral must also be considered in evaluating this installation, however, a final determination of the decreased extent and the value of this has not as yet been made. Seepage meter results indirectly indicate that the losses were reduced to between four-fifths and two-thirds the original amount, but the final rates of 0.9 cubic foot per square foot per day and greater seem to indicate that the experimental sedimenting produced only a partial sealing. The seepage meter method of evaluation, however, is not entirely reliable. The general water table conditions are at the lowest stage in 30 years, but this is in part due to local drought conditions. The total cost of the experimental work was about $11,000 or about 10 cents per square yard or about $1010 per mile of lateral. The average wetted perimeter of the treated section is about 18 feet.

<u>Kendrick Installation in Fractured Rock Materials</u> -- In this installation the intermittent reaches in fractured shale and sandstone are of primary interest, but some sealing was also obtained in sandy to silty slopewash. In this experimental installation the lateral conditions before sedimenting and the bentonite mixing operations were favorable, but the water running procedures were inadequate. Even though none of the reaches received an adequate ponding, some sealing was apparently obtained. No ponding tests were run so no estimate of water saved can be made. Seepage meter results indirectly indicate that the losses were reduced to between one-third and one-ninth the original rate. The final indicated rates range from 1.4 to 0.2 cubic

foot per square foot per day and seem to indicate partial sealing in some instances at the time of the testing. The cost of the experimental work was about $3,100. Because of the operational difficulties encountered no estimate of the cost per square yard is made.

College Phases of Research

With limited previous experience for a guide, "trial and error" methods were mostly resorted to in the initial experimental installation work at the field sites. Since many of the fundamental problems are now more clearly delineated, the fundamental or "diagnostic" research phases of the sediment lining development work have been initiated at Colorado A and M College. At this early stage, definite conclusions in most instances would be premature, but the general scope of the research work of the College phases of the program can be summarized.

Dispersion -- The College research work on the colloidal clay dispersions has included (1) testing of a trial and error nature to determine the amount and type of dispersant needed for each field installation, and (2) a long-range study of the dispersion characteristics of clay minerals mixed into various waters and including work on chemical dispersants. Most of the first dispersant testing was accomplished by the author at the field sites, and also some was completed by Mr. E. J. Acker at the College, by project personnel at the field sites, and by chemical and bentonite company personnel in their respective laboratories. A long-range cooperative program with the Technical Coordination Branch of the U. S. Geological Survey is being conducted through Dr. B. N. Rolfe, Clay Mineralogist, who has been stationed at Colorado A and M College. It is expected that a separate report of this year's long-range investigations will be completed shortly after July 1, 1955.

Mixing -- Another phase of the dispersion problem is the development of bentonite mixing equipment. This work has been accomplished by the Tri-County Project organization under the supervision of Mr. George E. Johnson, Chief Engineer, and the Cronese products Company of Tarzana, California. A limited amount of mixing research has been conducted at the College by two graduate fellows, Bruce Curry and Clive Newman, with equipment loaned by the Mixing Equipment Company of Rochester, New York. A make-shift but very economical method utilizing compressed air jetting into partially wetted bentonite has also been experimented with for use on intermittently-operated, small-size canals. In general, adequate methods for mixing bentonite for sedimenting purposes are available, but the costs could be reduced.

Penetration and Sealing -- As a supplemental activity to the small-scale feasibility testing performed at each field site, a College laboratory testing program has been conducted to determine why and how the sealing action takes place. The initial testing has been concentrated on laboratory sand materials. The fractured rock and loessial soil conditions would be more difficult and many times more expensive to duplicate in a laboratory apparatus set-up. R. B. Curry, graduate fellow, is conducting the study of the penetration and sealing processes under the direction of Dr. D. F. Peterson, Head of Civil Engineering Department, and Dr. B. N. Rolfe of U. S. Geological Survey. This fellowship has been financed by the bentonite company contributions. In the initial testing, penetration of suspended bentonite into the laboratory sands was achieved and indications of the controlling factors in the sealing were obtained. A continuation of this research is planned. The results will be in a master's thesis, to be completed before August 1, 1955.

Full flow methods -- The major installation work has been accomplished in lateral reaches where a slow ponding procedure could be utilized. In many canal systems, however, sufficient check structures are not available and the ponding procedure is consequently uneconomical. A limited amount of research work has been conducted by the College on the development of alternative procedures involving a full flow method of sedimenting. The work has been conducted on a lateral of the North Poudre Irrigation Company and possibilities of similar work have also been investigated for the Platte Vally Public Power and Irrigation District. Preliminary investigations have also been conducted for the Shell Irrigation Company through the Wyoming Natural Resource Board and the University of Wyoming.

Side Effects -- It has been recognized that bentonite sediment linings could produce effects other than sealing in the canal or lateral being sealed. One of the most frequent questions concerns the possible sealing effects that the bentonite could produce on irrigated soils. Research activities on this possibility were originally planned, but initial installation experience and precautions indicate that for practical purposes all of the bentonite is used in the canal being sealed. A normally muddy water could and commonly does spread much larger amounts of clay over irrigated lands.

Another possible side effect relates to the stabilizing effect that the colloidal clay material could have on fine non-cohesive materials, such as dune sands. A $500.00 grant has been made to Professor I. S. Dunn, who is studying this effect as part of a doctor's dissertation in preparation.

A third possible side effect relates to the effect on submerged water weeds. It seems that some varieties will not thrive in muddy waters. Thus, for a time it was felt that a periodic sedimenting procedure could be used in some instances for a combined purpose of water weed suppression and canal sealing. It seems likely, however, that in most instances this type of weed suppression would be too expensive.

Discussions and Conclusions

In the initial experimental installations, generally favorable results in sealing loess, dune sand, and closely fractured rock in canal beds have been produced, but the method has not been tested under a wide range of canal conditions. It is concluded that while the initial results are promising, especially from the standpoint of cost and ease of installation, the bentonite sediment method is still in the development stage. Many problems remain to be solved through research both in the field on actual canals, and in the laboratory.

The research and development problems being encountered in the initial cooperative sedimenting work are probably similar in many respects to those encountered in the development of earth dam construction procedures. In the first earth dams the earth materials were not carefully selected and construction was not carefully controlled.

Basic relationships were not understood. Today, after many years of development, earth dam construction is highly successful. This is only because a very specialized and closely controlled procedure has been developed over a long period of time. Similarly a long period of time and much effort may be required to develop the techniques necessary for successful application of sediment linings under widely variable canal conditions. Adequate research, however, should materially reduce the time needed to perfect successful sedimenting methods.

For the above reasons, the bentonite sedimenting method of sealing canals is not recommended for general use at this time. Where adequate technical help and facilities are available it is believed that the feasible limits of application for a given project area can be determined, but the results from one project area should be applied with caution in other project areas even if the conditions appear similar. Methods developed and problems encountered in the cooperative project work to date are presented in Chapters VII and VIII.

Chapter II

PROJECT ORGANIZATION

The potentialities of the bentonite sedimenting method were outlined in preliminary work by the Bureau of Reclamation field office at Casper, Wyoming. While the inherent advantages of the method were evident in this early work, it was also apparent that there were major research and development problems to be solved. Development of the techniques require experience from among several fields of engineering and science, viz., irrigation engineering, colloidal chemistry, clay mineralogy, soil mechanics, drill mud engineering and other fields of practical experience and scientific knowledge.

Because of the diverse problems involved, it was felt that a broad-based cooperative research approach was required. Thereupon, the Bureau of Reclamation and the Colorado A and M College entered into a contract agreement to initiate the cooperative sediment lining development project with provisions for admitting additional interested participants.

General Program

The general cooperative project program as outlined in the initial contract is summarized below:

1. Determine, by prior field and laboratory investigations, methods and materials to be used in sediment lining of canals and laterals in bed materials such as loess, dune sand, alluvial sands and gravels, and fractured sandstone and shales.

2. Install several demonstrational sediment linings in canal or lateral reaches, each representing one of the bed materials mentioned above.

3. Evaluate the effectiveness of the linings in preventing or retarding bed erosion and water loss.

4. Evaluate detrimental or beneficial changes in soil structures of lands irrigated by canals or laterals which have been sediment lined.

5. Mutually share all available technical data relevant to sediment linings.

Responsibilities and Financing

The initial contract outlined specific work items to be accomplished by the College through a project leader acceptable to both parties. It provided that the College would be reimbursed in an amount not to exceed $9,375.00 for project leader planning and assistance activities pertaining to the Bureau installation phases of the program and during fiscal year 1954. The author, who as a Bureau employee had worked on the preliminary sediment lining investigations, was employed as project leader by the College. The renewed contract for fiscal year 1955 operations covers a slightly wider range of reimbursable activities by the College, and the maximum amount of the contract was increased to $12,000.00.

The initial project funds were closely restricted to the Bureau installation phases of work. The initial contract, however, outlined several basic or fundamental research problems, to be worked on by the College provided financing from other sources could be obtained.

The contract also indicated that the Bureau laboratories would perform the applied research aspects of the preliminary development work required for the Bureau field site installations provided personnel were available. As it developed, the Bureau was able to do most of the required applied research. During the busy spring season of 1954, however, some College research money was expended on applied research work relating to the field installations. Thus, a strict division of separate work spheres, the one of applied research performed by the Bureau and the other of fundamental research performed by the College, has not been feasible.

The research and development work has been accomplished where the active interest, facilities, and support could be found. The initial College research work therefore was of an applied nature. Some of the Bureau laboratory work was of a fundamental research character, and some of the best applied research work has been accomplished at the field sites by field personnel. The Tri-County work has been especially helpful. Some of the research problems have been conducted directly by several of the cooperating bentonite, chemical, and mixing companies and by the U. S. Geological Survey. In some respects, therefore, the serious lack of research funds, personnel, and facilities has been an advantage in that it has produced a broad-based support for and interest in the sediment lining work. Dealing with so many different people, however, also has had its disadvantages.

During the past year and half the following sums of money have been received by the College Research Foundation for sediment lining research work:

Irrigation Districts (4 at various amounts)	$2,520.00
Bentonite Companies (5 at $500 each)	2,500.00
Bentonite Mixing Company (one)	500.00
Chemical Company (one)	500.00
	$6,020.00

In addition, 810 sacks (100 lb each) of bentonite and numerous samples of chemical dispersants have been donated to the College project. Significant contributions of technical information, particularly regarding chemical dispersants, have been received. The sediment lining expenditure by The Central Nebraska Public Power and Irrigation District (Tri-County Project) is not included above -- $15,000 in 1954, probably about $12,000 in 1955.

The funds received for research activities at the College -- exclusive of project leader activities and financing covered in the Bureau contracts -- have been budgeted as follows:

Dispersion Research		
Pertaining to field installations		$1,920.00[1]
Cooperative research by USGS		1,000.00[2]
Penetration Research		
Bentonite fellowship		2,500.00[3]
Stabilization Research		
Grant		500.00
Uncommitted Standby Fund		100.00
	Total	$6,020.00

[1] Full-time employee, discharged when funds expended; does not include contract support by the Bureau to this salary for the months of July, August, and September, 1954.

[2] Another $1,000 due July 1, 1955 -- amount, however, is covered by potential collections from a non-federal contract.

[3] Will be expended by about July 1, 1955.

Chapter III

REVIEW OF PREVIOUS WORK

The general problem of canal seepage and the high cost of canal linings have been briefly mentioned in Chapter I. For the convenience of readers not directly engaged in irrigation or related industries, more details of the general problem are outlined in this chapter. This is followed by sections relating to (1) example set by silting, (2) preliminary sediment lining work (prior to organization of cooperative project), and (3) review of literature.

Canal Seepage Problem

Of the water annually diverted for irrigation in the 17 western states, it is estimated that 35,000,000 acre-feet or about 40 per cent is lost before it reaches the farm (21). On 46 operating projects constructed by the Bureau of Reclamation it was determined that, on an over-all basis, approximately 25 per cent of the diverted water was lost in transit (20). In addition, the growth of supplemental irrigation in many of the remaining states is making the problem of seepage losses from unlined gravity flow distribution systems a problem of increasing national importance.

In most unlined canal systems, 10 to 60 per cent of the diverted water is lost prior to delivery to the farmer's field. Most of the loss consists of seepage from the canal banks and bottom. While this seepage water is not physically destroyed, it is seldom available for use by those who divert or pay for it. Large storage and delivery

The number in parentheses is the entry number in the Bibliography.

facilities are required to handle the extra water that must be diverted into the canals to compensate for the delivery losses. In many instances, however, the extra water or canal capacity is not available, and during periods when irrigation water is most needed, a shortage may occur.

In drought years this seepage water, if recovered, could be used to reduce crop losses, ranging from outright failure to planting and irrigation cut-backs. Perhaps of greater economic importance than the value of the lost water is the seep damage produced in nearby lands. The seepage from unlined canals serving hydroelectric generators results directly in energy and monetary losses. Considering all aspects of the seepage problem, the economic losses undoubtedly total millions of dollars annually.

The prospects are that the over-all seepage problem will increase in magnitude. This potential increase is related to the trend toward clearer irrigation water supplies. In many areas muddy irrigation waters are becoming less common owing to the increased use of pumped well waters and to the construction of upstream soil conservation, flood control, and irrigation storage structures. Consequently, the bad effects of excessively sandy sediments are being excluded from many irrigation canals, but unfortunately, the good effects of the colloidal clay content are also being eliminated. The resulting clear waters have caused extensive problems of increased seepage, bank erosion, and growth of submerged water weeds (16). Thus, at a time when the demands on available water supplies are producing critical shortage problems in many areas, the delivery problems in many canal systems are being aggravated by the trend toward clearer waters.

High Cost of Canal Linings

Seepage losses may be satisfactorily reduced through the installation of relatively impervious linings or by special treatment of the canal section, but the costs of generally accepted and dependable types of canal linings have long been prohibitive for most irrigation systems. In many instances, by ignoring the seepage losses, large cash capital investments have been avoided initially, though not actually, inasmuch as extra costs are eventually involved such as, seep damage payments, digging and maintaining drainage ditches, or constructing and pumping from drainage and irrigation wells.

Normal unit costs of canal linings recently installed on Bureau of Reclamation projects are listed below:

Type of Lining	Cost per sq yd
Unreinforced concrete (2 in. to 5 in. thick)	$2.00 to $5.00
Asphaltic concrete (2 in. thick)	2.00 to 3.00
Buried asphalt or bentonite membranes	.80 to 2.00
Heavy compacted earth (over 2 ft thick)	.40 to 1.00
Thin compacted earth (up to 2 ft thick)	.17 to .50

These costs vary over a wide range from one canal to another depending to a large extent on the availability of suitable local materials and the procedure required to install properly, protect, and adapt the canal lining to the site conditions. Optimum utilization of local materials and conditions can produce significant savings, but the costs may still be prohibitive in view of the magnitude of the large canal lining programs confronting many irrigation enterprises. In many areas, however, the high cost of conventional canal linings can be afforded and small sections of lining are being placed each year. It seems likely that many irrigation systems will eventually be entirely lined, but in the meantime there will be serious losses of water occurring from unlined canal reaches.

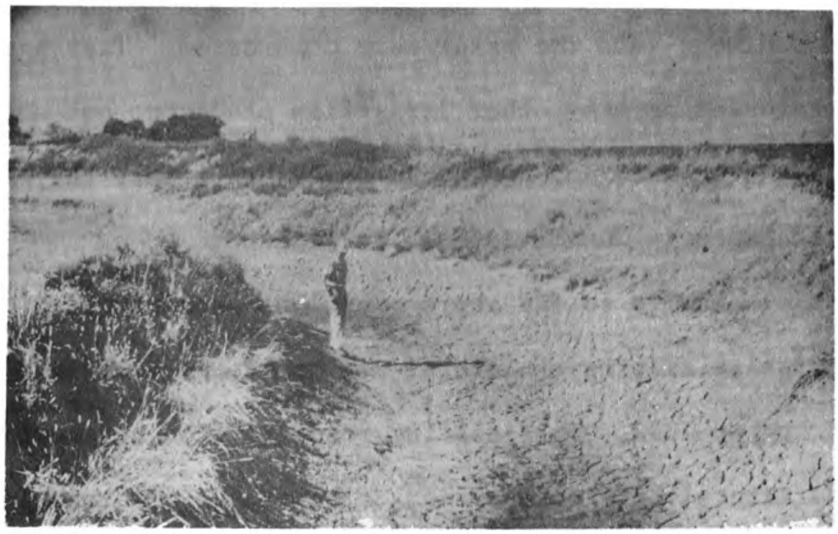
Example Set by Silting

Natural silting is about as old as irrigation. It has been commonly noticed that muddy water seems to go farther than clear water in ditches and on irrigated land. Usually, however, the disadvantages of a very muddy irrigation water such as the deposition of sand, which has to be removed by canal cleaning operations, far overshadow the advantages. Frequently, the advantages go unnoticed until canal cleaning or construction of an upstream dam emphasizes that there were, after all, some beneficial aspects to the muddy water.

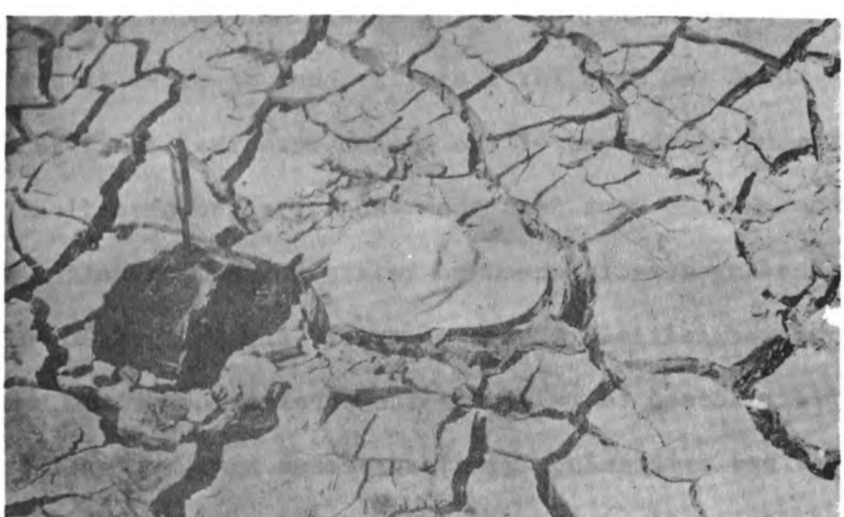
For example, after Guernsey Dam was completed, the amount of sediment in the irrigation water of the North Platte Project, Wyoming and Nebraska, was greatly reduced. The canal cleaning problem was significantly reduced, but a serious increase in canal seepage losses, severe bank erosion, and growth of submerged water weeds were experienced. Enclosure 1 of the Appendix compares the canal losses and farm deliveries of the Interstate Division for the period of 1914 to 1952. Storage of water in Guernsey Reservoir was begun in 1927.

In recent years the sealing effect of infrequent muddy water flows in the Interstate Canal has been noted and reported on by the project personnel. A slight mud content in the water (maximum about 1,000 ppm) will reduce the over-all Interstate Canal losses from 600 cfs

Plate 1 Natural Sediment Linings



Natural sediment cake in canal as a result of muddy irrigation water. Cracks were formed during a two-week period after water was shut off in Superior Canal -- Bostwick Unit, Nebraska and Kansas.



Close-up view of sediment cake.
Note layering of sediment. Cracks extended to depths in excess of 12 in.

to 500 cfs[2]. The normal maximum flow is about 2,100 cfs at the headgate. The sealing effect is temporary, however, lasting one week before the silt cake is eroded away. Thus, the possibilities of artificially introducing a sediment into the water were considered. They have similarly been considered on many other irrigation projects, but what kind of sediment should be used and how could penetration into the canal bed -- with consequently longer life -- be produced?

Partial answers to the above questions were provided by an accidental bentonite silting of lateral 218 on the Kendrick Project during the spring of 1952. This silting resulted from having to run water down the lateral before a section of bentonite membrane lining near the head end of the ditch was completed. The bentonite had been placed and partially spread, but had not been covered. The bentonite piles in the canal bottom acted as dams which were successively overtopped by the initial surge of water down the lateral. The initial release of water reached the end of the lateral in about eight hours as compared to about two days for a similar head of water in previous years. Indications at the end of the season were that the 1952 season losses were about 20 per cent less than those for the preceding season.

The sealing effect seemed to relate to the bentonite, which was picked up by the initial release of water, and the longer life of the sealing effect seemed to relate to the penetration of the bentonite into the lateral bed materials. Similar success with bentonite silting has been experienced on the Belle Fourche Project, South Dakota: a

[2] Personal communication from Mr. G. H. Storm, Superintendent, Pathfinder Irrigation District, Mitchell, Nebraska.

wetted bentonite membrane in the lateral bottom was stirred-up by a chaining method.

An examination of the reports on silting results from various projects shows that silting procedures with even a relatively pure clay, such as bentonite, are sometimes unsuccessful. Why are the results unpredictable and how could more controllable results be obtained? Data regarding the type of "silt"[3], quality of water, depth of sediment penetration, etc., from past examples of silting are practically non-existent. However, the normal characteristics and inherent limitations of many silting procedures can be generally outlined.

Limitations of Silting

The most common limitations of "silt" linings, such as the short life and unpredictable results, seem to relate in most instances to the character of the local material, which is either dumped or sluiced into the canal being lined. The common limitations of the local "silt" materials are listed below:

1. Permeability of material -- In some extreme cases, sandy and silty materials have been used for silting that are of a pervious nature, but even the most favorable appearing clayey materials from local deposits commonly tend to produce relatively permeable and vulnerable "silt" cake linings.
2. Settling tendency -- When mixed in untreated canal water, most local clays will tend to settle to the canal bottom

[3] Catch-all term -- generally means any sediment ranging in size from sand to silt to clay.

within a relatively short distance of flow, especially when they are inadequately dispersed in a hard irrigation water.

The settling can be attributed in part to the larger particles of silt and sand size, which are found in varying amounts in all natural clay deposits, and in part to the flocculent effect on the clay fraction of normal irrigation water. Either condition will result in coarse particles that readily fall out of suspension, depending on factors such as the canal water turbulence and the effective size of the sediment particles. The settling condition can produce two very significant limitations:

1. Transportation and deposition of "silt" -- The transportation of the "silt" sediment and the deposition of the "silt" lining become a function of water turbulence. All of the suspended sediment load may be dropped in the first ponded reach of canal and the lining action will be concentrated where the canal water conditions are most favorable for sediment settling and deposition, and not necessarily where the lining is needed.
2. Penetration and sealing by "silt" -- Many "silt" linings do not penetrate into the pervious canal bed materials. Because of the difference in fall velocities, the larger sediment particles, such as sand, tend to settle out of suspension first. This is unfortunate since just a small percentage of over-size sediment particles can produce a bridging action over all but the very largest void

openings in the pervious materials, thus preventing penetration of the smaller clay particles, which settle at a slower rate. Even if most of the particles of sand and silt sizes are eliminated, flocculation effects commonly produce flocculated aggregates of colloidal clay particles that could also bridge over void openings. Thus, the more colloidal clay, which probably produces the main sealing effect, is commonly concentrated at the canal bed surface, where it is susceptible to water erosion, puncturing by animals, deterioration by drying and cracking, or destruction by canal cleaning.

Preliminary Sediment Lining Work

Preliminary work on a more controllable type of silting was begun at the Bureau of Reclamation office in Casper, Wyoming, where the author was formerly employed as district geologist. The main problem in most silting work seemed to relate to the sediment settling effects. Thus, the work was concentrated on the control and elimination of the settling effects and on the development of more predictable penetration and sealing results.

The first testing was done in the district soils laboratory. From the previous field observations, it seemed that bentonite offered the best possibilities of producing a stable sedimenting mixture[4], and, to verify this conclusion, a few test mixes were run with a drilling

[4] For the purposes of this report -- silting is a process in which the sediment settles into place. In sedimenting or sediment lining the sediment is essentially stably dispersed; settling is virtually eliminated by one or a combination of methods, such as pre-settling, chemical dispersion, or water turbulence.

mud type of bentonite. The mixes were essentially stable after the non-colloidal content settled out of suspension. Permeability tests were then run on a number of soil samples: first with clear water, then with a 2 per cent bentonite mixture, and finally, after removing the surface cake of bentonite, with clear water again. The results of the testing are summarized in enclosure 2 of the Appendix (5).

Since the apparent percolation rates for the sedimented samples were significantly reduced, it was assumed that the bentonite had penetrated the sample. After clearing the preliminary investigational results with the Regional and Chief Engineer's offices, a field trial was run during the spring of 1953 in lateral 218 of the Kendrick Project. The first problem, however, was concerned with the bentonite mixing. As a result of a previous bentonite grouting job, the difficult nature of bentonite slurry mixing was well known. The problem was partially solved by contracting the mixing of the 75 tons of bentonite (dry) to a drilling mud control company. The treated lateral is about 8.2 miles long and has an initial capacity of about 80 cfs. Enclosure 3 of the Appendix summarizes the details of the test installation.

The conclusions from this installation work are:

1. Mixing method -- The high-pressure oil well cementing equipment produced lumpy mixtures of bentonite with the canal water.

2. Ponding procedures -- It was estimated that about one-third of the 75 tons of sedimenting bentonite was carried entirely through the lateral system and was

Plate 2 Preliminary Kendrick Project Work

Bentonite slurry mixing operation for initial sedimenting experiment. Slurry being diluted by flow of clear water over weir(Sta 2+56, lat 218).
May 6, 1953

Existing check structures utilized for ponding the mixture. Ponding interval was about 6 to 10 hours.
May 7, 1953

Plate 3 Preliminary Kendrick Project Work — Continued

Bentonite filter cake in lateral bottom after ponding interval with sedimenting mixture. Irrigation deliveries were begun several weeks later.
May 8, 1953

Clear water remained in low sections of lateral for about a week after the sedimenting. Before treatment, the lateral dried up within a day or so.
May 15, 1953

still suspended in the water leaving the terminal waste-ways. It was felt that with experienced ditch-rider help and slower ponding procedures a more efficient and trouble-free operation could be obtained.

3. Post-sedimenting procedures -- Directly after the sedimenting, the lateral was allowed to dry out. To allow sufficient time for bentonite penetration, it was thought advisable to maintain maximum water depths (with existing check structures) until normal irrigation deliveries were begun. (Subsequent work has not proved or disproved this postulation.)

4. Penetration of bentonite -- During an examination of the lateral bed, just after the sedimenting and in the better ponded areas above the checks, bentonite could be found in the fractures of the sandstone bed materials. In the sandy lateral reaches, the bentonite could not be detected visually but positive reactions were obtained in most instances with benzidene staining test. Many local soils have a natural bentonite content so that the staining test results were not conclusive.

5. Reduction of seepage loss -- Some reduction of loss was noted in the season delivery records, but it was evident that while ditch-rider records are sufficiently accurate for their intended use, they are not very satisfactory for determining seepage losses.

Review of Literature

Since the formation of the cooperative College project in July of 1953, a literature search has been carried on for information pertaining to the sediment lining method. Considerable information of a relevant nature has been found. (See Bibliography.)

Several reports of silting and grouting applications indicate the major importance of maximum particle size in the sedimenting charge and its relationship to penetration into the voids of pervious materials. Experience from the drilling mud control industry indicates that the depth of collidal bentonite penetration into the voids, to some extent, is a function of the viscosity of sedimenting mixture. A brief survey of literature on the general subjects of secondary oil recovery, soil physics and chemistry, colloidal chemistry, geology of ore deposits, and foundry clays seems to support the above generalizations and indicate that the sealing and stabilizing functions of an infiltrated clay could be related to the cumulative effects, in varying extents, of filtration, flocculation, adsorption, gelation, and ionic effect.

The earliest recorded work with bentonite slurries used for linings was devised and supervised by Mr. Charles H. Lee in 1929. Chenery Reservoir, used for storage in the San Francisco, California water supply system, was temporarily sealed by a method involving the use of a relatively concentrated bentonite slurry introduced directly on the lake bottom, beneath clear water.

During the investigation for the All-American Canal in 1939, the Bureau of Reclamation conducted tests in a hydraulic model in which bentonite, mixed in canal water without a dispersing agent, was caused to flow over a layer of canal soil. The bentonite was deposited in a thin layer on the soil surface. Upon drying, the bentonite layer on the soil surface cracked and curled up. When water was reintroduced in the model the sealing effect of the bentonite layer had been lost. It seems possible that this result was caused by over-size sediment particles, related to (1) the over-size non-colloidal content of the bentonite, and (2) flocculation agglomerations of colloidal clay particles. The latter condition could have been produced by the water, which probably was hard to some extent. Also, if the water circulation caused movement of the sample bed material, it could prevent penetration by the bentonite.

Chapter IV

INSTALLATION MATERIALS AND PROCEDURES

The major experimental installation work has been concentrated on the use of high-swell bentonite sediments in three carefully selected reaches of lateral within operating canal systems. The general aspects of the sedimenting materials and procedures, which apply equally as well to all three installations, are treated in this chapter.

Sedimenting Material

It is recognized that a great many colloidal materials fulfill the stably-dispersed and sealing-in-depth criterion for a sedimenting material. For example, colloidal iron oxide and other mill tailings wastes have been known to seal rather coarse grained sands and gravels. Stack dust from the manufacture of Portland Cement also seems to have possibilities, but of the commonly available and economical colloids, the colloidal clays offer the most promise as a satisfactory sedimenting material.

It seems possible to control and use locally available clay materials -- and site clays were investigated -- but in the initial work it was expedient and more economical to use commercial grades of bentonite. These are reasonably uniform in quality, in good supply, and in common usage. The past uses of bentonite as a canal lining material and as a sedimenting material also indicated its general desirability as the sediment to be used in the experimental installations, but some bentonites are better than others for sedimenting purposes.

Bentonite as a sedimenting material-- Bentonite is a generalized term which refers to a rather heterogeneous substance, composed mainly of the clay mineral montmorillonite and fragments of feldspar, gypsum, calcium carbonate, quartz, and traces of other minerals (1,7). It is thought to have been commonly but not exclusively derived from the chemical alteration or weathering of volcanic ash which was deposited in sea water. Its chemical composition can vary to a considerable extent, but a highly colloidal nature seems to be one distinguishing feature common to all high-swell bentonites. It is the colloidal yield of the potential sedimenting material that is of importance in the presently restricted sediment lining work.

The colloidal properties and incidentally the stable dispersion potential of a high-swell bentonite seem to relate to the very small size and inherent negative charge of the dispersed particles. The inherent charge is important since small size alone apparently is not enough to produce the desired stable dispersion feature. The character of the adsorbed cations is also a determining factor. When speaking of bentonite, therefore, it is necessary to keep in mind the two general classes: (1) those with a high ratio of sodium to calcium that can absorb large quantities of water, swelling greatly in the process, and remain reasonably dispersed and suspended in thin watery concentrations, and (2) those with a low sodium to calcium ratio that can adsorb much smaller quantities of water, do not swell greatly, and have a pronounced tendency to flocculate rapidly and settle from dilute suspensions in water.

When dispersed in a relatively pure water, a high-swell bentonite will commonly yield 70 to 90 per cent of particle sizes finer than

0.6 microns (about 1/42,500 of an inch. Local clays, particularly those of the Kaolnite and illite types, are commonly deficient both in small particle sizes and high exchange capacity. Even with chemical treatment they will seldom yield over 50 per cent of colloidal sizes.

A good high-swell bentonite can absorb nearly five times its own weight in water and at full saturation or hydration it occupies a volume 12 to 15 times its dry bulk. The swelling is reversible; it can be wetted and dried an infinite number of times if the water is fairly pure. When mixed with 7 to 10 parts water, it makes gelatinous pastes which will gel or set-up; with 15 to 20 parts of water milky, flowable suspension is formed; and in very dilute mixtures, such as 1 part bentonite to 100 parts of water, a high percentage of the bentonite particles will remain in suspension almost indefinitely if the water is nearly pure or salt free. The latter concentration and condition are of interest in the present sediment lining work.

Bentonite deposits or beds are found in many parts of the world, but the high-swell bentonites are found mainly in Wyoming, South Dakota, and Montana. The current prices range from $1 to $3 per ton, unprocessed at the pit and from $10 to $35 processed and sacked at the plant -- the higher prices usually include engineering service. Bentonites have a wide application in industry, but the principal uses are as a binding agent in foundry sands and as a major constituent of oil well drilling muds.

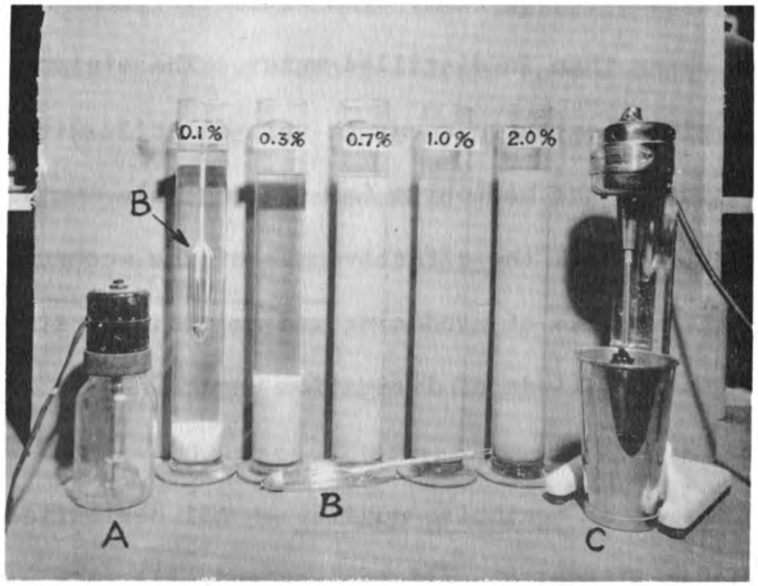
The drilling mud uses of bentonite are in some respects similar to the sediment lining applications. In the rotary drilling of wells, a "mud" is pumped down the drill pipe carrying the bit, to wash away cuttings and to raise them to the surface. The mud also functions to seal the walls of the hole and prevent water loss. Bentonite added to the drilling mud enhances its lubricating and wall-sealing properties and also, owing to its thixotropic or gelation properties, assists in keeping cuttings from settling in the holes in the event of a shutdown of the drilling equipment. The drilling muds are usually quite viscous in contrast to the more watery concentrations, which seem more applicable to sediment lining uses.

Other uses of bentonite include: as a thickening and suspending agent in medicinal, cosmetic, and pharmaceutical preparations; as a vehicle in horticultural sprays and insecticides; as a clarification agent for turbid water and sewage purification; as a gelatinizing agent in wet mash poultry and stock foods; and in the filtering and decolorizing of mineral and vegetable oils.

Provisions for stable sedimenting mixtures-- The economy and selectiveness of the sedimenting method depends on the sealing material being stably dispersed in the sedimenting charge of water. Since slow ponding procedures were to be adopted in the initial experimental work, special provisions were required to produce the desired stable conditions.

In the preliminary mixture testing, it was found that each particular kind of bentonite exhibits a characteristic minimum stable concentration in distilled water. This stable limit varies from a minimum of about 2 grams of a high-swell bentonite in a liter of distilled water to a maximum of over 50 grams of the least stable low-swell bentonite in a liter of distilled water. Concentrations of a given bentonite below its minimum stable concentration will rapidly flocculate

Plate 4 Dispersion of Bentonite in Water



Dispersion testing equipment and test mixtures (after 48 hours)
A 6-volt mixer for field testing. B Hydrometer. C Laboratory mixer.

Preliminary mixture testing, Horse Creek Lateral site
(immediately before mixing operation).

and settle out of suspension, leaving clear water above the settled bentonite.

Normally the stable limit of a bentonite is higher when dispersed in canal water than in distilled water. The minimum stable concentration of a given bentonite seems to vary directly with the multivalent cation content of the bentonite (as exchangeable ions) and of the irrigation water, and with the effectiveness of the mechanical dispersion method. Thus, the problem of producing and maintaining stable dispersions of bentonite in various kinds of irrigation waters may be subdivided as follows:

1. Control of bentonite quality -- All bentonites have some non-colloidal or grit content and will vary widely in their yield of dispersed clay particles of a colloidal nature. This lack of uniformity problem was controlled in the project work by buying high-swell bentonite of the following specifications:

Moisture	10% maximum
Grit (plus 325 mesh screen--wet)	6% maximum
Grind (plus 200 mesh screen--dry)	15% maximum
Yield, drilling mud basis (15cp)	85 bbl/ton min.
Dispersion test	No free water*

* 5 grams of bentonite uniformly dispersed in 1000 cc of distilled water -- no free water after standing undisturbed for 24 hours.

2. Control of hard water -- Since most irrigation waters are hard to varying extents, some tendency toward flocculation of the dispersed sedimenting bentonite will usually be encountered. With slow ponding sedimenting procedures the flocculation effects can seriously reduce the colloidal yield and the downstream extent of the sealing

action. Chemical dispersing or water softening agents can be used to control this problem. After considering a number of different dispersants, it was finally decided that the polyphosphates would be the most economical and effective agents; other agents, however, could be used. The polyphosphates seem to have a multi-purpose application, including the following:

a. Sequesters the multivalent cations in the water, thus inhibiting the exchange reactions involving the cations of the bentonite and the water and thereby retarding the flocculation and settling of the dispersed bentonite clay particles.

b. Reduces the viscosity of the bentonite slurries, thus facilitating the mixing and pumping operations.

c. Provides sodium ions to assist in dispersion of the clay colloid.

The polyphosphate was added at a rate of from 1/2 to 1 lb per 100 lb of bentonite. In the Bureau jobs it was added to the bentonite at the jet hopper, and on the Tri-County job it was added into the mix water ahead of the bentonite.

3. Control of mixing problem -- Producing large quantities of uniform, lump-free, and stable dispersions of bentonite in water is a difficult problem somewhat analagous to the problem of mixing water and flour. Lumps with partially wetted centers are commonly produced. Previous experience

with the single jet method used by the drilling mud industry indicated that it would be difficult to obtain satisfactory mixing by contract, but for the Bureau jobs there was no alternative. The work had to be contracted out. In contrast to the many problems encountered on the contract mixing jobs, the operation and the mixture produced by the multiple-jet set-up used on the Tri-County job was entirely satisfactory. Also the per ton mixing cost was about one-third the contract per ton cost.

4. Control of final concentration -- Under nearly dead-ponded conditions and because of the possibilities of further dilution, an effort was made to maintain the initial sedimenting concentrations above 1 per cent. Soil hydrometers[1] were used to determine the concentrations. Nomograms are included as enclosures 4 and 5 of the Appendix. They can be used to compute the quantities of bentonite and water required to produce a given concentration of bentonite mixture.

Thus, when necessary a stable sedimenting mixture can be produced by using a high-swell bentonite, softening the mix water, adequately mixing the bentonite into the water, and maintaining the initial sedimenting concentration at 1 per cent or greater.

Field Site Procedures

The selection of sites for experimentation follows three general requirements: (1) suitability of the lateral size, grade, and structure

[1] Two types have been used -- standard Bouyoucos hydrometer with range between 2 and 60 grams/liter and special sensitive hydrometer with 0 to 10 grams/liter range. (6).

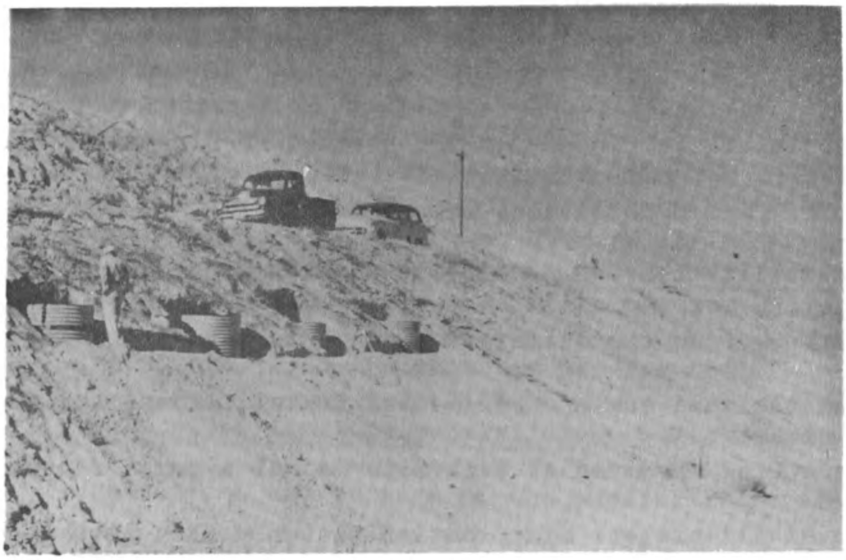
locations for installation, (2) presence of definite seepage problem through pervious material assigned for each site, and (3) availability of water for sedimenting, of wasting facilities, of technical help, and of operating help. It was not possible, however, and in some instances not necessary, to adhere closely to the general requirements. Some compromise to fit field conditions was required.

Feasibility testing -- A pilot model approach was used in the field site work -- from two different viewpoints. First, small scale tests preceded the full scale experimental installations; and secondly, the reach of lateral involved at each site is but a small representative part of the over-all project distribution system. Each installation was preceded by a comprehensive program of preliminary testing consisting of (1) a careful evaluation of the field site conditions under both flowing water and dry conditions, (2) establishment of "before lining" records of site conditions and seepage, (3) sample collection and Denver laboratory evaluations of canal waters, canal soils, and potential sediments (12), and (4) completion of small scale permeability and sedimenting tests at each site.

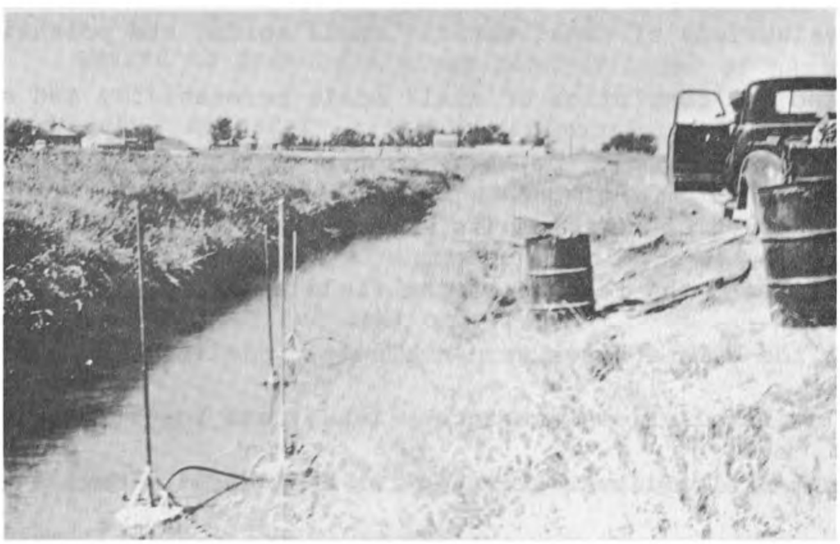
Evaluation of test results -- In a meeting of the Technical Advisory Committee[2], the results of the field and laboratory testing pertaining to the Bureau sites were evaluated, preliminary planning for the full-scale installations was accomplished, and the Tri-County non-Bureau site was officially substituted for the Bostwick Unit -- Courtland Canal site in the cooperative project program.

[2] Composed of two College members -- not including project leader -- and three Bureau members.

Plate 5 Field Site Feasibility Testing



Test pits for feasibility tests in loessial soils, Courtland Canal.
Permeability tests were run with clear and bentonitic water.



Seepage meter set-ups for feasibility tests in dune sand materials, Horse Creek Canal. Same equipment and procedure were used in Kendrick Project testing.

Final planning -- The final planning for the three installations consisted of (1) development of tentative installation plan for each site, (2) completion of additional dispersion tests to determine the type and amount of chemical dispersant to be used, (3) calculation of total volume of sedimenting charge for each installation, (4) preparation of final cost estimates, and (5) final preparations for delivery of water, materials, mixing operation, and ponding procedures. Tentative starting dates were set by backing up about two weeks from the expected starting date for irrigation water deliveries, but the actual starting date was finally determined by the Chief Engineer on the Tri-County Project and by the irrigation superintendents on each of the other two projects -- the weather, the conditions of the lateral, and the need for irrigation water being the determinants.

Installation work -- The order of work at each site was (1) presedimenting work, (2) bentonite mixing operation, (3) bentonite water ponding, and (4) follow-up and clear-water-drive phases of ponding until normal irrigation deliveries were begun.

1. The procedures varied at each site but in general the presedimenting work consisted of the following:

    a. Preliminary release and water storage -- On the Kendrick and Tri-County projects regular irrigation water was used for the sedimenting charge of water and for the follow-up drive of clear water. This required releases into the main supply canals serving the test site laterals several days to a week prior to the start of the sedimenting work.

On the North Platte project site, water from a local creek was used. Since the creek flow was only 3 to 4 cfs of water it had to be accumulated for over a week in the ponded reach above the mixing point.

b. Mix point and lateral preparations -- The mixing equipment was assembled on the head end of each lateral reach being treated and a mud pit was constructed. The bentonite and dispersant were delivered. Where possible, weeds were removed from the test reaches of lateral and the check structures were water-proofed. The latter step was required because the small sedimenting flow would leak through the normal check board structures.

c. Preliminary mixture testing -- Check mixtures were made with the bentonite, the dispersant, and site water in pre-determined proportions. The mixtures were allowed to stand for several days while visual observations and periodic hydrometer readings were taken. This furnished a check on the dispersion stability and also a calibration for the concentration control testing during the slurry mixing operation and for the follow-up check tests during the subsequent ponding phases.

d. Operating personnel -- Arrangements were made for inspectors on the contract mixing for the Bureau jobs. This was not required on the Tri-County work as they did their own mixing. Where possible extra ditch rider help was arranged for the water running phases of the sedimenting work.

2. The bentonite mixing operation at each site consisted of two general stages as outlined below:

a. Slurry mixing -- In all three jobs a relatively high concentration bentonite slurry was mixed by using the jet methods as previously mentioned. Even when the concentration ran as high as 10 per cent bentonite, the combination of cold water and polyphosphate dispersant produced a relatively low viscosity and easy flowing mud -- provided the mixing action was producing a smooth mix. On the Bureau contract jobs, many mixing problems were encountered that required supplemental jetting or gunning in the mud pit to complete the mixing. The mud pit cycle in the mixing provided (1) a control so that when necessary lumpy unsatisfactory mixes could be supplementally mixed by additional water or air jetting, (2) extra time for "curing" or complete hydration of the bentonite, and (3) a stand-by volume and better control for slurry additions to the lateral.

b. Slurry dilution -- The resulting slurry was then run into a diluting flow of relatively clear irrigation water. By taking periodic hydrometer check tests, the amount of diluting water was regulated so that the desired initial sedimenting concentration was obtained. Mixing difficulties on the contract mixing jobs, however, caused wide variations in the rate of slurry flow and quality. This, in turn, considerably increased the difficulties of regulating the concentration of the final sedimenting flow.

3. The actual sedimenting operation in the lateral reaches being treated can be subdivided into three general phases of work:

a. Routing of sedimenting water -- This critical phase of the sediment lining procedure was accomplished by the normal operating personnel in each project area. The normal water running sequence consisted of ponding back from the first check structure in each test section of lateral. Depending on the mix rate and volume of the first pond, this required from one to two days. After the first pond was filled, the bentonitic water was preferably released from under the check planks, at a rate equal to the inflow at the upper end of the pond. The procedure was repeated for successive ponds down the lateral being treated. Pond levels were maintained at uniform high levels as much as possible with the available ditch rider help.

b. Follow-up clear-water drive -- Upon completion of the mixing, the same small release of water was continued down the lateral so that the checked-up pond levels could be maintained as uniformly as possible and until full irrigation deliveries were begun. The objective of the full-depth and low-velocity conditions for as long as possible after the sedimenting was to provide a full opportunity for bentonite penetration into the pervious materials. Subsequent observations indicate that the major bentonite cake condition, and incidentally the least sealing effect, is concentrated in the first pond. This is where the non-colloidal fraction of the dispersed bentonite settles out of suspension.

c. Mixture stability tests -- The time required for the bentonitic mixtures to travel down the successively ponded reaches of lateral varied from about five days for the Kendrick job to about two weeks for the other two jobs. Owing to (1) an overrunning and diluting effect of the untreated follow-up water, (2) the pick-up of soil salts, and (3) in some instances, inept water running procedures, varying degrees of flocculation effects were noted, which tended to reduce the strength of the sedimenting mixture. To provide a record and a check of the sedimenting mixture, stability and general characteristics, periodic samples and hydrometer readings were collected at various water depths and locations. The samples were later analyzed in the Bureau laboratories. The dispersion stability, position, extent, and volume of the sedimenting charge at various times during the sedimenting procedure were charted by this procedure.

Final evaluations -- The most important evaluations concern the sealing effect produced, its life expectancy, and the amount, if any, of reclaimed land. In the treated section of the Tri-County lateral, a combination of before and after ponding tests and delivery records has been used to determine the sealing effect. On the Kendrick and North Platte installations a combination of seepage metering, ground water level measurements, and irrigation water records was used. Partial ponding test results are also available for the North Platte installation. Seep areas also enter into the North Platte and the Kendrick evaluations. Where possible, comparisons were made of the experimental lining cost against the estimated value of the water and land saved or reclaimed as a result of the sediment linings.

Chapter V

EXPERIMENTAL INSTALLATION RESULTS

The major experimental sediment lining installations of the present cooperative project program were made during April and May of 1954 just prior to the irrigation season. The evaluations contained herein, therefore, cover only the results after one irrigation season and are grouped in chronological order of installation: first, Tri-County; second, North Platte; and last, Kendrick. The Tri-County installation was accomplished entirely by project forces and equipment; the North Platte installation with contract mixing, Bureau inspection, and District water running, and the Kendrick installation by contract mixing and Bureau inspection and water running.

The third Bureau of Reclamation site in the Courtland Canal of the Bostwick Unit in Nebraska and Kansas has been investigated, but up to the present time no full-scale installation work has been planned because of the large size and uncompleted status of the over-all canal system and because the cooperative project objectives for an experimental site in loessial materials were fulfilled by the Tri-County work.

Loessial Site in Tri-County Project

In the Tri-County Project and other areas in Central Nebraska, the silty loessial materials are commonly characterized by a clay cement and by many vertical "root-hole" or tube-like voids (9). They have a relatively high permeability and, upon saturation, tend to densify and settle. Critical and dangerous conditions of foundation settlement and general instability can be produced (11), but on the B-65 main lateral system of the Tri-County Project the depth to water table throughout most of the area is in excess of 100 ft and, therefore, settlement has not as yet been a problem. The urgent need for canal lining in this system is created by high delivery losses, ranging from 80 to 50 per cent from beginning to end of the irrigation season, and a heavy demand for water that cannot be met by the present system.

Feasibility testing -- Since the Tri-County interest developed after most of the feasibility testing had been completed for the Courtland Canal site in loessial materials, the results were applied in the planning of the Tri-County experimental work. Of particular interest and applicability were the results from the permeability tests conducted in four test pits in the Courtland Canal[1]. The test results as summarized in enclosure 6 of the Appendix indicate that under controlled conditions (1) penetration and sealing of loessial soils with dispersed bentonite mixtures can be produced, and (2) the 2 per cent concentration of bentonite produced the best sealing and penetration results. Several major problems were revealed pertaining to (1) the equipment aspects of the mixing problem, (2) stability problems of dispersing high-swell bentonite in hard water, and (3) penetration problems introduced by natural silt cakes or by the sand and silt fraction of sedimenting mixtures.

With the above work as a background, the Tri-County work was immediately concentrated on (1) the design, construction, and field

[1] Testing involved the local project personnel, Mr. D. M. Lancaster of the Bureau Laboratories (13), and the author.

testing of a mixing equipment set-up, and (2) dispersion stability tests involving high-swell bentonite, canal site water, and chemical dispersants.

Owing to the District's silt injection operations, most of the equipment and experienced personnel were already available. The equipment, designed by Mr. George E. Johnson, Chief Engineer, The Central Nebraska Public Power and Irrigation District, is shown in enclosures 7 and 8 of the Appendix. It was field tested on February 8, 1954 by sedimenting a 2700-ft section at the head end of lateral 19.3 of the E-65 main lateral system. Enclosure 9 of the Appendix summarizes the details of this mixing trial. It was concluded that (1) the equipment was satisfactory, (2) additional laboratory testing was needed to determine the type and concentration of chemical dispersant required, (3) the concentrated slurry should be run through a mud pit, and (4) sedimenting sites in loessial soils should be as dry and weed-free as possible.

Preliminary planning -- In planning for the large-scale Tri-County installation, a site in the E-65 main lateral from Mile 23.7 to Mile 36.2 was selected because of the need for a dry lateral site. The mosaic pattern of drying cracks seems to help in the bentonite penetration. The design capacity of the lateral at Mile 23.7 is 100 cfs and, from over-excavation during cleaning operations, the remainder of the test section to Mile 36.2 is the same or of larger capacity. The bed material in the test reach is loessial soil, which is believed to be representative of widespread loessial conditions common to the Tri-County and other nearby project areas.

A slow ponding procedure of sedimenting was planned. Allowance being made for volume shrinkage from the sediment lining action, it was assumed that about 1,300,000 cubic feet of sedimenting water and 400 tons of bentonite would be required. The project calculations are summarized in enclosure 10 of the Appendix. To determine the amount of dispersant needed, final dispersion stability tests were conducted in the District laboratory at Hastings, Nebraska. The results of this testing are outlined in enclosures 11 and 12 of the Appendix. From this testing it was decided that sodium tripolyphosphate at a concentration of 0.75 per cent (by wt. of bent.) should be used.

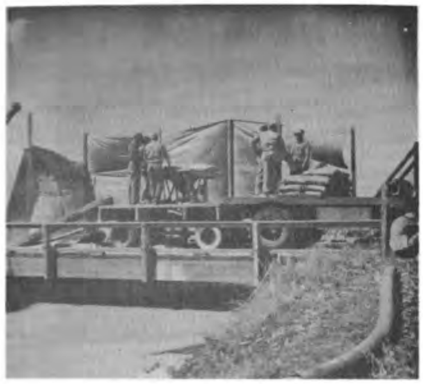
Installation work -- Most of the information in the following summary of installation work is from a report made by Mr. G. E. Johnson, Chief Engineer, to the Board of Directors, The Central Nebraska Public Power and Irrigation District, dated April 22, 1954.

The mix point was on the south bank of the main lateral near the turn-out structure at Mile 23.7 which is three miles directly north of Bertrand, Nebraska. Mixing was started at 3:30 p.m. on April 5, 1954 at a rate of 300 lb of bentonite into 400 gpm of ditch water. The dispersing agent -- sodium tripolyphosphate ($Na_5P_3O_{10}$) -- was added to the mix water before the bentonite at the rate of 0.6 to 0.75 lb per sack of bentonite. The clear mix water was pumped from the lateral above the turn-out structure and the slurry from the mud pit was pumped into a turbulent flow of diluting water being released into the test reach of lateral. The release was regulated so that a final diluted concentration of 0.7 to 1.0 per cent bentonite was maintained. The mixing was completed at 1:00 p.m., April 8, after 59.5 hours of actual mixing time with a ten-hour interruption from bad weather. A total of 403 tons of high-swell bentonite and 6000 lb of dispersant were used.

Plate 6 Tri-County Mixing Equipment

Overlapping views of mixing equipment set-up(enclosure 8 of the Appendix). Some extra stand-by equipment in field set-up is seen above.

Close-up view of multiple jet hopper(enclosure 7 of the Appendix).



Bentonite being unloaded directly from truck into jet hopper.

View of discharge line from jet, and holding pit and equipment.

View of pit and equipment.

Plate 7 Tri-County Sediment Ponding

Dry and cracked loessial materials in lateral bottom before sedimenting.

Initial Stage in sediment ponding. (Note wetted fringe.)

Close-up view of drying cracks and sedimenting mixture.

View of pond after full water depth was reached.

Mr. Johnson makes hydrometer check test, other man holding sampler.

Close-up view during hydrometer test of concentration of sediment mixture.

At the beginning of the mixing the lateral bottom was thoroughly fractured by drying cracks. The ponding phase of filling and then allowing an under-flow into the next lower lateral section was effectively controlled by having a crew burn weeds ahead of the sedimenting water and then water-proof each successive structure with dirt. When the mixing was completed, lateral sections 1, 2, and 3 (Mile 23.7 to 24.6, 24.6 to 26.0, and 26.0 to 27.9) were full of bentonite water. After the mixing, the same small flow of water used in the mixing (about 10 cfs total) was continued down the lateral as a clear water drive, which followed the sedimenting water down the lateral. Maximum pond levels were maintained during the sedimenting and until normal irrigation deliveries were begun.

At periodic intervals during the ponding, samples of water and hydrometer readings were obtained. The hydrometer readings are tabulated in enclosure 13 and the sample analyses (12) in enclosure 14 of the Appendix. At first hydrometer readings alone were taken, but as the nearly dead-ponded water started to warm, temperature readings were also required. Then as settlement and clear-water overrun effects became important, samples were collected from various water depths with an integrating sediment sampler. By April 16, after 11 days of successive ponding, a small amount of dilute (less than 0.4 per cent bentonite) mixture was left in section 8 (Mile 35.5 to 36.2). To clear the main lateral for irrigation deliveries, the remaining bentonite water was run into sub-lateral 36.2 and was ponded between Mile 0.3 and 0.9. All of the sedimenting bentonite was utilized in the system: there was no waste onto irrigated land.

The major problem encountered in this installation lies in the diluting and overrunning effect of the clear-water drive which followed the sedimenting water down the lateral. The overrun of untreated hard water caused some flocculation of bentonite. This problem could be controlled by softening the after-drive of clear water, or perhaps the after-drive could be eliminated entirely. The general absence of difficulties on this installation may be attributed to the planning and supervisory efforts of the project personnel. Mr. George E. Johnson, Chief Engineer, planned and supervised the over-all operation. Mr. Ted Johnson, Resident Engineer, and Mr. Jack Kapke, Canals Supervisor, supervised the mixing operation and Mr. Orin Marquardt, Division Superintendent, and Mr. A. F. Lepik, Resident Engineer - Superintendent, were directly responsible for the ponding phase of the sedimenting work.

The costs of the experimental bentonite sediment lining installation in the E-65 main lateral are outlined below:

Total cost of bentonite at job* (403 tons at $23.00)	$9,269.00
Total cost of mixing (403 tons at $10.00)	4,030.00
Total cost of ponding, engineering, etc.	1,701.00
Total Cost	$15,000.00
Unit cost -- approx 200,000 sq yds at $15,000	$.075/sq yd
Cost per foot of canal -- approx 12.5 mi at $15,000	$.23/ft
Cost per mile of canal -- approx 12.5 mi at $15,000	$1,200/mi

* includes cost of dispersant, freight, and hauling costs.

<u>Initial results</u> -- Most of the information in the following summary of initial sediment lining results is from a report by Mr. G. E. Johnson to the Board of Directors, The Central Nebraska Public Power and Irrigation District, dated December 6, 1954.

The before and after measurements of seepage in the treated sections were accomplished with ponding tests. The before ponding test was made with normal irrigation water at the end of the 1953 irrigation season; the same test was repeated at the end of the 1954 irrigation season. The treated sections were filled to 6 inches above the normal operating level and an earth barrier was placed in front of each check structure with a dragline. In the testing for both years, the time for a 12.5-in. drop from the normal level was recorded for each section. The ponding tests are outlined in the table below:

E-65 Section	Mile Stations From	To	Time for 12.5" drop in pond level hrs	Approx Loss* cu ft/sq ft/24 hrs
1	23.7	24.6	83	0.30
2	24.6	26.0	74	0.34
3	26.0	27.8	117	0.21
4	27.9	28.7	89	0.28
5	28.7	31.3	136	0.18
6	31.3	32.7	115	0.22
7	32.8	35.4	162	0.15
8	35.4	36.2	162	0.15
	Total Miles	12.5	Avg 117	Avg 0.21
Loss for 1953 (before sedimenting)			Avg 24	Avg 1.04

1954 Check tests in untreated sections of nearby branch laterals

Branch lateral	From	To	hrs	cu ft/sq ft/24 hrs
30.6	0.0	0.4	14.5	1.72
			15.0**	1.67
			16.0**	1.61
35.0	0.0	0.5	16.0	1.56
36.2	0.3	0.9	34.0***	0.74

* Includes evaporation losses
** Pond pumped full again after preceding test and time for 12.5-in. drop from normal water level measured again.
*** Dilute mixture of about 0.2% bentonite wasted into this lateral at end of sedimenting.

Thus, the after treatment losses at the end of the 1954 season, which average 117 hours for a 12.5-in. drop or about 0.2 cu ft per sq ft per day, were about one-fifth of the before treatment losses at the end of the 1953 season, which averaged 24 hours for the same 12.5-in. drop or about 1.0 cu ft per sq ft per day.

A significant fact is that the sealing effects were greater in the lower canal reaches, where the strength of the bentonite suspension and the ponding time was less. It would seem that the more colloidal sedimenting mixtures produced a better sealing effect. The non-colloidal materials probably settled out in the first two ponds.

The ponding results indicate that the following amount of water was saved by the sedimenting during the 1954 season:

36.809 acres(water surface area of treated section[2])x(1.0 - 0.2)x180 days

= 5,300 acre-ft

5,300 acre-ft x $15.00 = $79,500

The $15.00 value per acre-ft of irrigation water to the water user is based on project figures. The actual value according to State-Federal statistical comparisons of gross crop income from irrigated land against dryland is about $40.00 (37).

The results of two comprehensive field examinations of the lateral bed indicate that the bentonite sealing effect was concentrated along old drying cracks, loess tubes, and crayfish holes. In most instances the bentonite was found in these larger voids from the surface

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[2] Actual measurement by project, based on average of widths at 500-foot stations along treated reach.

and extending to depths greater than one foot. From petrographic examinations of loess samples from the treated sections, it would appear that little to no bentonite penetrated into the micropores of the soil. This seems reasonable because the sedimenting action is concentrated in the zones where the major loss of water occurs. It seems unlikely that any major loss of water is occurring through the micropores of the loessial soils.

<u>Dune Sand Site in North Platte Project</u>

In the North Platte Project area and other similar areas in Wyoming and Nebraska, the wind-deposited dune sand materials are commonly characterized by a relatively uniform grading of fine-grained sand particles. The dune sands are usually quite pervious, free of clay, and cohesionless. When exposed in a canal bottom, they produce high water loss problems and, unless the canal grades are very flat and the cross-section shallow and wide, extreme bank erosion may take place.

The North Platte Project experimental installation was made on the Horse Creek lateral from Mile 7.6 to 20.9. The capacity of the lateral at Mile 7.6 is about 100 cfs and at Mile 20.9 it is about 40 cfs. The main ponding with bentonite water was from Mile 9.1 to Mile 20.0. The intermittent canal reaches in dune sands are most prevalent from Mile 13.0 to 19.6. The intervening reaches of lateral are excavated into fractured siltstone and sandy to silty slopewash. The need for lining this lateral was related to the seepage areas in adjacent lands, caused by high lateral losses -- a large part of the losses occurring in the dune sand reaches.

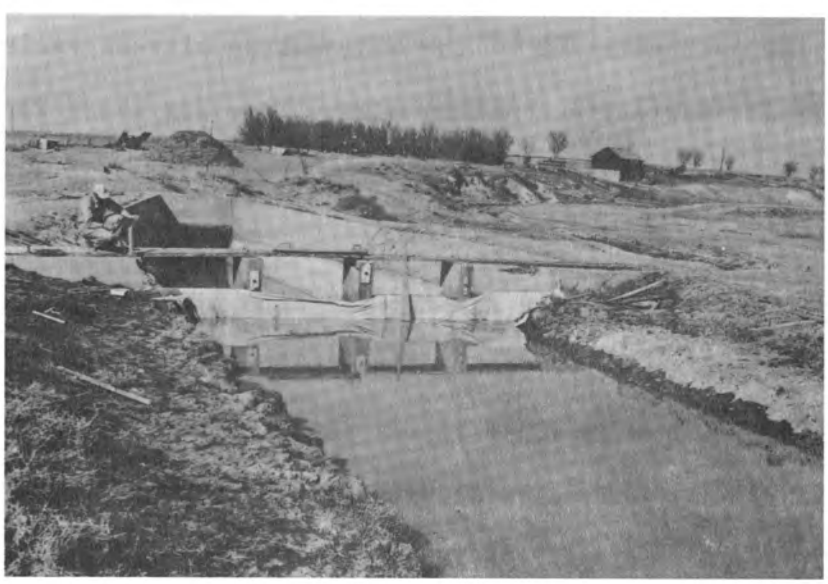
Feasibility testing -- The preliminary feasibility tests with bentonite sedimenting mixtures were originally discussed as Denver laboratory testing, but the wide variety of lateral bed materials and conditions made this approach inadvisable. The tests were run in modified seepage meters set in the operating lateral. Enclosure 15 of the Appendix summarizes the test results. It was concluded that under controlled conditions (1) penetration and sealing of dune sand materials can be produced and (2) the one per cent mixture of bentonite produced the best sealing effect. Dispersion stability problems were revealed that indicated a need for additional testing. Also the presence of a natural silt cake on the lateral bottom indicated that the sedimenting mixture should be run into a dry lateral: drying will crack the silt cake and allow penetration of bentonite mixture.

Preliminary planning -- A slow ponding procedure was planned. It was calculated that about 200 tons of bentonite would be required to treat the lateral. Available funds restricted the amount of bentonite to 175 tons. The pond volumes of the lateral and the bentonite calculations are outlined in enclosure 16 of the Appendix. Preliminary mixture stability tests with the normal irrigation water and high-swell bentonite indicated that 1 per cent of dispersant (by wt. of bent.) was required. Since the tripolyphosphate and tetrasodium pyrophosphate produced about the same effect for equal concentrations; the latter was chosen for economy.

Installation work -- Most of the information in the following summary of installation work is from an unpublished Bureau of Reclamation report dated May 26, 1954 by Mr. W. K. Lundgreen, Soil and Moisture Conservation Engineer, Torrington, Wyoming.

Plate 8 North Platte Project Installation

Equipment set-up for mixing. Temporary holding pit constructed so that mixing could be completed. Pump on left used for supplemental jetting.



Initial filling of pond at Mile 11.0.
Note canvas for water-proofing and mixture testing by man on structure.

The contractor set up his mixing equipment on the north bank of the lateral near the check structure at Mile 7.6, which is about 1/2 mile east and 3 miles south of Lyman Nebraska. Mixing was started at 10:00 a.m., April 23, 1954 and, because of mixing difficulties, ran intermittently until 4:00 p.m., April 26, 1954. The mix rate varied over a wide range from less than 1 ton of bentonite per hour to as much as 9 tons per hour into 100 to 300 gpm of mix water. The dispersant was added with the bentonite at the jet hopper at a rate of 1 lb to each sack of bentonite.

The clear mix water was pumped from the lateral pond backed up from the check at Mile 7.6. The slurry was added into a diluting flow of clear water released at the check structure. Because of the lumpy character of the bentonite slurry, an earth dike was bulldozed across the lateral below the check structure, and, by supplemental jetting in this improvised mud pit, a satisfactory sedimenting mixture was produced. The concentration of the sedimenting mixture varied from 1 to 2 per cent bentonite. Actual mixing time was about 78 hours total bentonite mixed was 175 tons; and total dispersant used was 3,300 lb.

At the beginning of the mixing, the conditions in the lateral were not entirely satisfactory: the lateral was partially full of drain waters from Mile 9.1 to about 15.0. Thus, in some reaches the natural sediment cake, which can block the bentonite penetration, was not thoroughly dry and cracked. In addition, toward the end of the mixing, a heavy rain and snowstorm produced a large runoff of surface water into the ditch. The dilution of the sedimenting mixture was not a problem since the initial mixture concentration was set at 2 per cent with the dilution possibility in mind, but the flow of runoff water into the untreated lateral sections did intensify the wet lateral problem. The ponding procedure for sedimenting process in the Horse Creek lateral was similar to that used in the Tri-County work except that earth plus canvas was used to water-proof check structures.

At periodic intervals during the ponding phase of the sediment lining procedure, samples of water and hydrometer readings were obtained. The hydrometer readings are tabulated in enclosure 17 and the sample analyses in enclosure 18 of the Appendix. By May 10, 1954 and after 18 days of succesive pondings the sedimenting charge was almost completely spent. A small amount of very dilute (less than 0.5 %) mixture was left in section 11 between Mile 20.0 and 20.9. By the time normal irrigation was begun, all the bentonite had been used up in the lateral or sub-laterals.

The major problems encountered in this installation related to (1) mixing, (2) wet lateral conditions, and (3) shortage of ditch rider help. The mixing problems may be ascribed to (1) inexperienced mixing personnel, (2) inadequate mixing equipment and, (3) the chemical quality of the drain water used for the sedimenting. The presence of high-sodium drain waters in the lateral ahead of the sedimenting mixture probably detracted the bentonite penetration through the natural silt cake and into the underlying pervious bed materials. While the problems above were serious, the harmful effects were largely minimized by a considerable amount of extra effort by Mr. W. K. Lundgreen, the

Bureau engineer in charge of the job, and Mr. T. P. Winchell, Superintendent of the Gering and Ft. Laramie Irrigation District.

The costs of the experimental bentonite sediment lining installation in the Horse Creek Lateral are outlined below:

Total cost of bentonite (175 tons at $18.50)		$ 3,237.50
Total cost of dispersant (3,900 lbs. at $0.0963)		375.57
Total cost of mixing (175 tons at $31.68)		5,554.00
Inspection and overhead (assumed 10 % of above)		915.70
Water running costs		170.40
	Total Cost	$10,253.17

Note: Unit cost on an over-all yardage basis was about 10 cents per sq yd, but for pervious areas the cost was probably nearer 15 cents per sq yd.

<u>Initial</u> <u>results</u> -- Most of the information in the following summary of initial sediment lining results is from an unpublished Bureau of Reclamation report by Mr. W. K. Lundgreen, dated October 11, 1954.

During and immediately following the sedimenting it was evident that a very effective initial sealing had been obtained. The loss with the lateral at maximum ponding depths from Mile 9.1 to 20.0 was not over 4 cfs. This was a total loss including seepage, turn-out gate leakage, and evaporation. An effort is being made to have the same ponding done this spring. Exact "before lining" loss figures are not available, but according to the superintendent, the losses before sedimenting ranged as high as 10 cfs per mile in the dune sand reaches and at the start of the irrigation season. The lateral receives drain inflow and waste waters from up-slope irrigation; therefore, most of the delivery records cannot be used for determining losses.

The only weir measurements considered to be reasonably reliable were made at Mile 14.3 and Mile 25.0. This reach covers about the last half of the treated section and 5 miles beyond. Indications are that the over-all losses in the reach were about 15 per cent in 1953 and about 10 per cent in 1954 after part of the section was sedimented.

Seepage meter tests were made in several reaches of the lateral at 100 to 200-foot intervals and before and after the sedimenting. The results are summarized in the following table:

Mile Sta. From	To	August 1953 No. of Tests	Seep. Avg*	August 1954 No. of Tests	Seep. Avg*	Per cent decrease or increase	Remarks
9.3	10.0	40	2.7	40	1.8	-33	Silty to sand slopewash
11.1	12.2	39	3.0	39	2.5	-17	Sandy silt over Brule siltstone
15.1	17.1	39	1.2	60	0.9	-25	Dune sand
20.0	20.9	30	1.7	30	2.3**	+35	Silt and sand

* Seepage in cu ft/24 hrs/sq ft
** Received virtually no bentonite water ponding

Observation wells were established during the summer of 1953 below the test site so that the effect of the lining on the ground water table could be determined. The periodic observations were started in August 1953 and have been continued till now. A set of 1953 readings and a set of 1954 readings are shown below:

Well No.	8-19-53* ft	8-23-54* ft	Remarks
22-58- bbb	8.7	9.6	.75 mile N of Mi 9.1
22-57-18bbb	5.6	10.2	.3 mile N of Mi 10.0
22-57- 7aab	8.6	14.0	.1 mile N of Mi 11.9
22-57- 6aaa	8.4	13.5	.6 mile NW of Mi 12.8
23-57-33cbc	8.7	7.5	1.0 mile NW of Mi 15.2
23-57-33dcd	1.4	2.7	.8 mile N of Mi 15.2
23-57- ccc	2.7	5.1	.5 mile NW of Mi 16.5
22-57- 3bab	3.8	6.3	.3 mile N of Mi 16.5
22-57- 1aba**	5.1	4.9	Just below lateral at Mi 20.1
22-57- 1aab**	5.0	5.1	.1 mile NE of Mi 20.1

* Depth to ground water table from surface of ground
** Opposite reach of lateral that did not receive full ponding

Thus, the seepage meter results and the water table measurements indicate that the sedimenting had a definite sealing effect, but both methods give indirect seepage results. The water table and the seepage lakes of the area below the treated section are both at the lowest levels in 30 years, but the unusually dry conditions of 1954 also seemed to have contributed to this condition. Additional long-time evaluations, including a ponding test this spring, may help to define more accurately the sedimenting results.

The observed penetration of bentonite, both in the laboratory samples and in field examinations, into the lateral bed was variable. The bentonite in the drying cracks was readily visible, but the bentonite in the voids of the sandy materials could only be detected by laboratory methods. The latter determination is not entirely satisfactory because the presence of native bentonite in the sands makes detection of the sedimenting bentonite somewhat uncertain. In general, a penetration of over 1 ft in trace amounts seemed to have resulted in most instances.

Fractured Rock Site in Kendrick Project

In the Kendrick Project and other similar areas in Wyoming, fractured shale and sandstone are commonly found as canal bed materials through which loss of irrigation water occurs. This loss of water may contribute to seepage problems in nearby irrigated lands. On the Kendrick Project the seepage alleviation may be more important than water saving.

The Kendrick Project experimental installation was made in lateral 128. The design capacity of the lateral from station 0 + 00

Plate 9 Kendrick Project Installation

View of mixing equipment

View of hopper where bentonite and dispersant was added to water.

View of mud pit and gravity line to lateral

View of slurry addition point. Diluting flow released over weir.

View of bentonite water ponding.

View of temporary structure at Station 90 + 00 ±.

to 179 + 00 (in feet) is 50 cfs, but the maximum flow to date has been about 20 cfs. The important reaches are those traversing fractured shale and sandstone from station, 2 + 56 to 29 + 75 and 63 + 31 to 96 + 00.

Feasibility testing -- The preliminary feasibility tests with bentonite sedimenting mixtures were run in the operating lateral with modified seepage meters. Enclosure 19 of the Appendix summarizes the test results. It was concluded that under controlled conditions (1) the penetration and sealing of closely fractured rock materials with bentonite sedimenting mixtures could be produced, (2) the one per cent mixture of bentonite produced the best sealing effect. Dispersion problems were revealed that needed additional laboratory testing and study.

Preliminary planning -- A slow ponding procedure was planned, but because of the relatively steep grades of the lateral; a supplement check structure at about station 90 + 00 was planned. It was calculated that about 175,000 cu ft or at one per cent concentration, about 54 tons of bentonite would be required. Additional dispersion tests were run and it was found that one per cent (by wt. of bent.) or about 1,100 lbs of tetrasodium pyrophosphate would be required.

Installation work -- The contractor set up his mixing equipment on the north bank of lateral 128 and just below the main canal. The mix location was approximately 20 miles southwest of Casper, Wyoming. Mixing was started at 10:30 a.m., May 13, 1954 and, because of mixing difficulties, ran intermittently until 3:00 a.m., May 14, 1954. The mix rate varied from about 4 tons of bentonite per hour into about 200 gpm of water to about 8 tons per hour into about 400 gpm of water. The dispersant was added with the bentonite at the jet hopper at a rate of one pound to each sack of bentonite.

The clear mix water was pumped from the lateral pond backed up from the head weir at station 2 + 56. The slurry was run through a culvert from the end of the mud pit into a diluting flow of water flowing over the head weir. Supplemental jetting in the mud pit was required when the mix rate exceeded about 4 tons per hour, but the final mix in the lateral was reasonably satisfactory. Actual mixing time was about 16.5 hours; total bentonite mixed was 55 tons; and total dispersant used was 1,000 lb. Initial sedimenting concentration was about one per cent.

The ponding procedure was disrupted by (1) a break-out through an old bentonite membrane over a badly fractured rock zone at about station 29 + 00, (2) two successive wash-outs of a temporary check structure at about station 90 + 00, (3) excess leakage through the water-proofed structures at stations 96 + 50, 113 + 50, and 149 + 00, and (4) ditch rider help available for only a few hours each day during the sediment ponding procedure. None of the reaches, with possible exception of the first reach, received adequate ponding. These difficulties produced dilution and flocculation problems so that virtually all of the bentonite had settled out of suspension by the morning of May 17th.

At periodic intervals during the ponding phase of the sedimenting procedure, samples of water and hydrometer readings were obtained. The hydrometer readings are tabulated in enclosure 20 and the sample analyses in enclosure 21 of the Appendix.

The costs for the experimental work are outlined below:

Total cost of bentonite (55 tons at $15.25)	$ 838.75
Total cost of dispersant (1,200 lb at $.1002)	120.24
Total cost of mixing (55 tons at $29.90)	1,479.00
Inspection and overhead (estimated at 10 % of above)	243.80
Water running costs (assumed)	400.00
Total Cost	$3,081.79

Because of installation procedure and seepage evaluation problems, it is difficult to determine the treated lateral area, therefore, no estimate of cost is made.

<u>Initial results</u> -- Most of the information in the following summary of initial sediment lining results is from an unpublished Bureau of Reclamation report by Mr. W. K. Lundgreen, dated October 11, 1954.

Some sealing effects resulted from the partial sedimenting of lateral 128. Ditch rider delivery records, both before and after the sedimenting, are tabulated below:

Date	Flow at Sta 2+56 cfs	Per cent of Total Lost in Reach Sta 2+56 to 112+68	Sta 112+68 to 148+78	Sta 148+78 to 178+50	Per cent of Flow Lost in Reach
8-23-53	16.8	13.8	6.9	3.1	23.7
8-28-53	17.3	9.5	5.1	3.2	17.7
8-31-53	16.8	11.9	6.8	1.3	20.1
9- 3-53	16.3	12.9	7.6	1.9	22.3
9-10-53	15.6	7.1	5.4	0.9	13.3
9-13-53	14.4	16.6	1.9	14.9	33.4
9-28-53	7.8	8.1	9.0	2.3	19.4
9-29-53	5.6	+0.2	9.3	19.9	29.0
7-20-54	10.9	7.0	4.6	2.1	13.6
7-25-54	10.9	7.0	4.6	2.1	13.6
7-30-54	15.6	3.5	5.5	2.5	11.5

While the above table indicates that less water was lost during 1954 than 1953, the records are not detailed enough to calculate water saved by the sedimenting. The losses by seasons are tabulated in the following table:

Lateral	1948	1949	1950	1951	1952	1953	1954
128 and Subs.							
Inflow*	274	259	1136	1981	2873	3197	3863
Deliveries and Waste*	120	125	908	1609	2383	2509	3251
Loss*	154	134	228	372	490	688	612
Per cent Loss	56.2	51.7	20.1	18.8	17.0	21.5	15.8

* Units are acre-feet

Seepage meter tests were made in several reaches of the lateral at 100 to 200-foot intervals and before and after the sedimenting. The results are tabulated below:

Stations in ft From	To	Aug. 1953 No. of Tests	Seep Avg*	Aug. 1954 No. of Tests	Seep Avg*	Per cent decrease or increase	Remarks
2+00	19+00	18	2.0	18	1.4	-30	Silt, some bedrock
20+00	26+00	7	1.3	7	.4	-69	Fract. shale and sandstone
65+00	78+00	14	1.9	10	.2	-89	" " " "
79+00	94+00	16	2.9	-	-	-	" " " "
96+00	148+00	27	2.6	28	.9	-65	Sandy silt slopewash
150+00	174+00	13	2.3	12	3.0**	+30	

* Seepage in cu ft/24 hrs/sq ft
** Bentonite flocculation very pronounced in this reach owing to overrun and dilution by the after-drive of clear untreated water.

Thus, the seepage meter results indicate a general trend toward lower seepage rates in the reaches that received partial sedimenting. Values obtained with the seepage meter are only relative, however, and cannot be used to calculate directly the water saved.

Observation wells were established immediately below the lateral so that the effect of the sedimenting on the indicated ground water levels could be obtained. The depth-to-water readings were begun on September 1, 1953 and have been continued to date. A few of the sets of readings are tabulated on the following page.

Well No.	Sta	9-1-53	1-29-54	5-11-54	5-20-54	6-15-54	7-13-54	9- 2-54	9-22-54
1	10+00	12.4	24.7	24.1*	24.1*	21.7	21.7	15.6	17.6
2	21+50	1.9	15.2	15.6**	10.8	3.1	2.6	1.8	1.9
3	30+50	-0.3	7.5	9.2	-0.6	-1.4	-2.2	-3.0	-3.0
4	64+50	0.0	0.2	0.0	-0.0	-0.2	-0.2	-0.2	-0.5
5	100+00	5.9	6.4***	6.4**	6.4***	6.3	5.2	5.2	5.9
6	114+50	5.1	14.9	14.8	14.7	8.1	6.7	5.2	5.6
7	118+00	13.0	13.0	13.1	13.1	13.1	13.1	11.9	12.8
8	178+00	10.0	17.2	17.8**	17.8**	16.5	11.1	8.1	8.7
9	239+00	18.7	18.9**	18.8***	18.8***	18.8***	18.8***	18.8***	18.8***
10	276+00	16.8	17.0	17.1	17.1	17.0	-	-	-

* Damp
** Mud
*** Dry

Note: Negative depth indicates water level above ground surface. Sedimenting started 5-13-54, water in canal more or less continuously until end of September.

Thus, in over half of the wells the indicated water table was slightly higher after the sedimenting than before. The reasons for this are difficult to visualize, but it does seem that only a partial sealing effect was obtained and that the sedimenting bentonite may have migrated to considerable distances in the fractures of the shale and sandstone bedrock materials.

The laboratory staining tests on six drive samples collected from the lateral bottom reveal that the bentonitic suspensions have penetrated into the canal bed materials: (1) in fine to coarse grained sands up to 18 in. in small to moderate amounts and (2) into the less pervious silty to clay materials in only small amounts and limited penetration. A field evaluation of the amount and character of penetration has not been made as yet.

Notwithstanding the inadequate ponding procedure followed in the experimental installation, there is some doubt as to whether a satisfactory sealing could be accomplished in some of the more open fractures even with adequate ponding. Coarser size sediments may be required to bridge the larger voids in badly fractured rock; and higher concentration of bentonite in the sedimenting charge may be necessary for successful sealing.

Chapter VI

INITIAL FUNDAMENTAL RESEARCH RESULTS

Since neither Federal nor State support has been available for fundamental research work on the sediment lining method, fund raising and organizing of cooperative research work were the first order of business. This has taken time, but a good start on the fundamental research program has now been made. For the most part definite conclusions would be premature at this early stage, but where possible the initial results are summarized in the following sections. Each section has been written by the man or men largely responsible for the work.

Dispersion Characteristics of Clay Minerals

by B. N. Rolfe, U. S. Geological Survey

Introduction

The research program on dispersion of sedimenting colloids was undertaken to determine the factors affecting suspensions and their relation to sediment lining.

The calcium-sodium relationship in the colloid-canal water system affects the stability of clay suspensions. Under conditions of slow flow and ponding the feasibility of sediment lining and the need for chemical deflocculents depend, in part, on this relationship. A brief discussion of the reasons for this effect may be in order.

Flocculation and dispersion represent end stages in a long sequence. Repellent and attractive forces are active in colloidal suspensions. The primary components of these forces are: (1) electrolyte content of the water, (2) kind and amount of cations present, (3) kind and amount of colloid. The attractive forces are proportional to the electrolyte content of the water; the effect is slight at lower concentrations but increased sharply to coagulation at higher concentrations. The amount of electrolyte needed for flocculation will vary with the kind of ions involved. Generally, the coagulant effect varies with ionic valence. For example, less trivalent aluminum is needed for flocculation than divalent calcium or univalent sodium. Thus, the kind and amount of cations present must be considered. Sodium is generally regarded as a dispersant but will induce flocculation when present in sufficient concentration. The third factor in clay suspensions is the mineralogical nature of the colloid. Clay minerals such as montmorillonite have a large specific surface and cation exchange capacity. Kaolinite exhibits reverse properties, having a small specific surface and cation exchange capacity. The response of these two minerals to changes in aqueous environment is strikingly different. For example, the effect of a native cation on kaolinite is negligible whereas that on montmorillonite is significant. The clay titration curves of the two minerals differ, neutralization occurring at different pH values.

Flocculation occurs when the forces of attraction dominate, thereby causing coagulation. The sudden change in particle size in a hitherto dispersed mix may cause a fall-out, probably aided by contact adsorption between newly-formed aggregates and suspended fines. Present data indicate that the calcium-sodium ratio of the suspension may hasten or delay this straining action. The time element involved in the interplay of forces is important.

Dispersion takes place when the repellent forces dominate over the considered period of time. During deflocculation, the inherently negative charge of clay particles is satisfied mainly by cations with large spheres of hydration and high zeta potentials. The net effect is to keep the clay particles discrete and separated. It is likely that dispersion is aided by concurrent viscosity changes which impede the fall velocity of the discrete particles.

It is therefore apparent that the dispersion problem is exceedingly complex. During the preliminary experimental stage, the variables were restricted whenever possible. Colloid concentrations were confined to one per cent, suspensions were monomineralic and clay saturations were homoionic. The variables studied were quality of water and chemical deflocculents.

Purpose

The purpose of the program is to study the dispersion characteristics of colloidal sediments in waters of varied hardness and the effect of chemical deflocculents thereon.

Scope

Materials -- The materials of the investigation consisted of three components: colloid, water, and deflocculent.

1. Colloid

   Reference clays from each of three principal clay mineral groups were studied. A brief description of the three groups follows.

Particle Size Range	Clay Mineral Group	Structure	Cation Exchange Capacity	Swelling Potential
Colloid--fine clay<1u	Montmorin	2:1 lattice	high	high
Fine--coarse clay<2u	Mica	2:1 lattice	moderate-low	moderate-low
Coarse clay--fine silt<20u	Kaolin	1:1 lattice	low	low

   The reference clays from the groups were:

   (a) montmorin - Volclay, a high-swell, Wyoming bentonite, containing the clay mineral, montmorillonite, distributed by American Colloid Company.

(b) mica - Fithian illite, type clay mineral of this group, from Illinois.

(c) kaolin - Georgia kaolinite, distributed by the Georgia Kaolin Company, Dry Branch, Georgia.

2. Water

The waters were synthetic and within the range of irrigation waters tabulated in Handbook No. 60 of the USDA Salinity Laboratory, Riverside, California. Anions were not considered a variable at this stage of the investigation. Calcium and magnesium sulfate were used along with sodium chloride. The bicarbonate ion was not included. The following table presents the chemical composition of the two synthetic waters used in the dispersion experiment.

	Hard	Soft
pH	7.0	6.9
TDS (ppm)	3445	1400
Ca (meq/liter)	17	3
Mg (meq/liter)	8	2
Na (meq/liter)	17	$15\frac{1}{2}$
% Ca and Mg	59	24
% Na[1]	41	76
SAR[2]	4.8	10
ESP[3]	6	12

[1] % Na SSP - soluble sodium percentage

$$\frac{Na \times 100}{Na + Ca + Mg}$$

[2] SAR sodium adsorption ratio

$$\frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

[3] ESP exchangeable sodium percentage

$$\frac{\text{exchangeable Na(meq/100 gm soil)} \times 100}{\text{cation exchange capacity(meq/100 gm soil)}}$$

The USDA Salinity Laboratory investigated equilibrium relations between soil (colloid) and irrigation waters. They arrived at an empirical parameter, namely, the sodium adsorption ratio, which indicates the probable replacing power of an irrigation water with respect to the soil exchange complex. This ratio, defined in footnote to Table 1, hereinafter referred to as SAR, provides an index to the expected composition of the exchange complex at equilibrium. The ESP value or exchangeable sodium percentage, defined in footnote 3 to Table 1, therefore defines the cation relationship on the exchange complex. In the present investigation, the ESP values of the various clay minerals at maximum dispersion will be determined. This will yield information on the equilibrium Ca-Na ratios on the exchange complex of stable suspensions.

3. Deflocculent

The sediment lining method is dependent on the long-range availability of colloidal suspensions in canal reaches. The effect of hard water on the dispersion characteristics of clays has been discussed. The colloid-water environment must be beneficiated to overcome the coagulant influence of hard waters.

Commercial phosphate deflocculents improve the dispersion environment by sequestering the divalent cations like calcium and magnesium and replacing them with sodium.

This action consists of tying up the calcium and magnesium as complex phosphate ions, so that they are soluble and unavailable for reaction with the clay. Introduction of the sodium aids dispersion as described previously.

Three commercial deflocculents were used during the course of the experiment. These were (1) sodium tripolyphosphate, (2) sodium hexametaphosphate, and (3) a 50-50 mixture by weight of sodium hexametaphosphate and soda ash.

Methods -- The three clay minerals were made homoionic with respect to calcium and sodium by respective saturation with 1N calcium acetate and sodium chloride. Ten grams of the saturated clay were then placed in 1,000 cc of distilled water plus dispersant. Maximum dispersion of the clay suspension was considered effective when the peak amount of colloidal particles was recorded, i.e., the hydrometer reading at the twenty-six hour interval was at a maximum. The size distribution curve of a clay mineral under standard dispersion conditions was a reference goal toward which suspensions of the same mineral in synthetic waters were directed.

Chemical deflocculents were added in small amounts to the colloid-synthetic water mix until the zone of maximum dispersion was reached or approximated. The pH of the suspension was then determined and the colloid saved for later determination of exchangeable cations. The large amount of phosphate in the suspension made it difficult to determine soluble ions in the water. The competition between the phosphate and versenate[1] for calcium and magnesium caused interference during

[1] Commonly used for determining calcium and magnesium content in water analysis procedures.

the determination. It was therefore decided to analyze the colloid for exchangeable cations at the conclusion of the dispersion run. The ESP value for each clay mineral in stable suspension will then be computed.

Results and Discussion

The experimental program for the 1955 fiscal year is not completed. The data indicate the importance of the mineral composition of the sedimenting colloid, its exchange cations, quality of canal water, and kind and amount of deflocculent used. Results thus far point to the complexity of the Ca-Na clay-water system, especially at high electrolyte concentration.

A final report on the year's dispersion research will be published shortly after July 1.

Future Research

The program to date has been concerned with end members of the Ca-Na system in exchange cations and in canal waters. Clays have been homoionic with respect to calcium or sodium; synthetic waters have been hard or soft.

Future research will be directed toward the investigation of field prototypes in colloid and water. The native Ca-Na ratios of a Wyoming bentonite such as Volclay will be taken as standard and Ca-Na of exchange ratios for illite and kaolin will be adjusted accordingly. Similarly, a low grade native bentonite with a different Ca-Na ratio will be used and the illite and kaolin so adjusted.

The synthetic waters will be patterned after such prototypes as Tri-County and Horse Creek sedimenting waters. This will yield a contrast in waters as in this year's work and, additionally, will produce data pertinent to a particular field installation.

The present investigation indicates that there is close relationship between viscosity and dispersion. A decrease in fall velocity of particles may be accomplished by decreasing the size diameter, by increasing the viscosity of the medium, or by a combination of the two. Apparently, maximum dispersion represents the coincidence of peak values for least size diameter and viscosity increase. Future research will be directed at analysis of the water chemistry at stages during a dispersion test along with determination of the suspension viscosity at similar times. It may be possible to develop this relation to the point where simple viscosity tests will indicate the degree of dispersion of a colloid-water mix.

Summary

Clay minerals from the montmorin, mica, and kaolin groups were made homoionic by saturation with calcium and sodium solutions. One per cent concentrations of the saturated clay mineral were then suspended in synthetic waters of varied chemical composition. The effect of kind and amount of commercial phosphate deflocculent was studied. A report of this year's investigation will be completed shortly after July 1, 1955.

Studies of Penetration and Sealing

by D. F. Peterson and R. B. Curry

Introduction

The long-range study on penetration and sealing has as its objectives rather fundamental research on two important aspects of the sediment lining process: (1) to determine conditions under which bentonite particles in suspension will penetrate a soil matrix and, (2) to determine conditions under which these particles will be deposited in the soil pores. For the first phase of the work herein reported only simple sands and stable suspensions of high-swell Wyoming bentonite in distilled water were used. This restriction was made in order to reduce the number of variables to a minimum and to allow examination of these variables under simple and thus more readily interpretable conditions.

Analysis of the problems of penetration and sealing lead to some rather obvious hypotheses. Once the bentonite particles are transported to the desirable location and the suspension passes through the sand pores, they might be filtered out by simple physical filtration to form a surface filter cake, they might be deposited immediately in the first thin layer of sand, they might penetrate rather deeply, or they might simply pass on through the sand without deposition, or some combination of the foregoing might occur. As far as sands are concerned, the first practical question to be answered is under what conditions penetration can be expected.

The second phase of the problem is concerned with sealing by deposition of the bentonite in the pores of the sand. One might suspect that this could be accomplished by either adhesion of the bentonite to the sand particles or by the formation of flocs within the pores. Factors which might have bearing on this phenomenon would appear to be the sand grain size, the surface activity of the sand grain, the drag forces on the bentonite particles resulting from seepage, and the chemical environment of the bentonite particles. By choosing inert sand, the surface activity of the sand is essentially eliminated and the chemical environment of the bentonite particle remains fixed. Chemical theory and experience leads to the belief that adhesion or flocculating forces are more predominant under a calcium environment than under the sodium environment existing in the stable suspension. One might thus infer that sealing could be improved if the calcium component of the suspension could be increased once the sand pores have been penetrated. Thus the current experiments contemplated some attempt at providing available calcium in the sand for some of the runs.

While rather basic in their nature, the current experiments were designed with some practical application in sight. Field soils tend to have a describable effective size as far as permeability and filtration potential are concerned. Furthermore, most soils of the region tend to possess available calcium -- this is probably true even of the high-sand soils such as the dune sands -- likewise some surface activity probably exists in even the coarsest and cleanest sandy soils found extensively in nature.

Laboratory Tests and Results

Detection of bentonite -- As a tool for evaluating the sealing aspect of the study, some means of detecting the bentonite deposited in the pores was necessary. After considering a number of possibilities, benzidine staining was adopted. This stain produces a bright blue color in the presence of bentonite, and very small amounts can be detected readily. While satisfactory for these tests because there was no bentonite in the test sand, the benzidine test would not appear useful for soils that contain bentonite naturally.

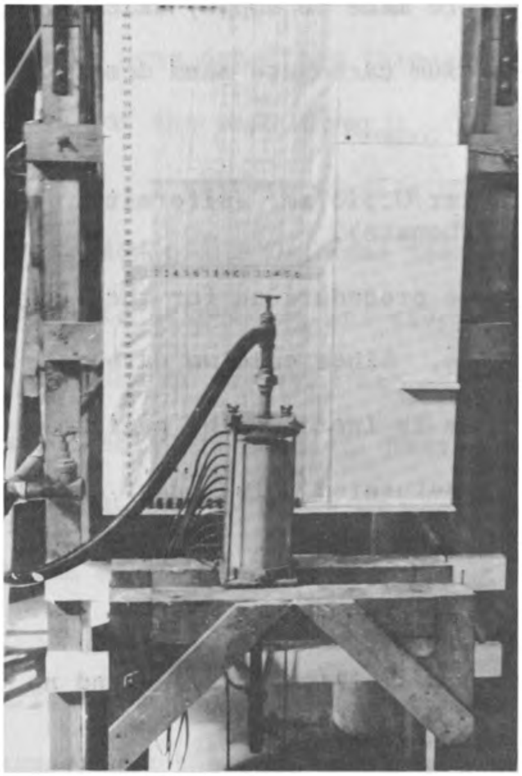
<u>Tests on inert sands</u> -- The following sands were used:

1. Ottawa sand, median diameter 0.480 mm, uniformity coefficient 1.08 (almost spherical).
2. Loup River sand, median diameter 0.280 mm, uniformity coefficient 1.50 (rounded).
3. Barton sand from Loveland Lake, median diameter 0.160 mm, uniformity coefficient 1.80 (angular).

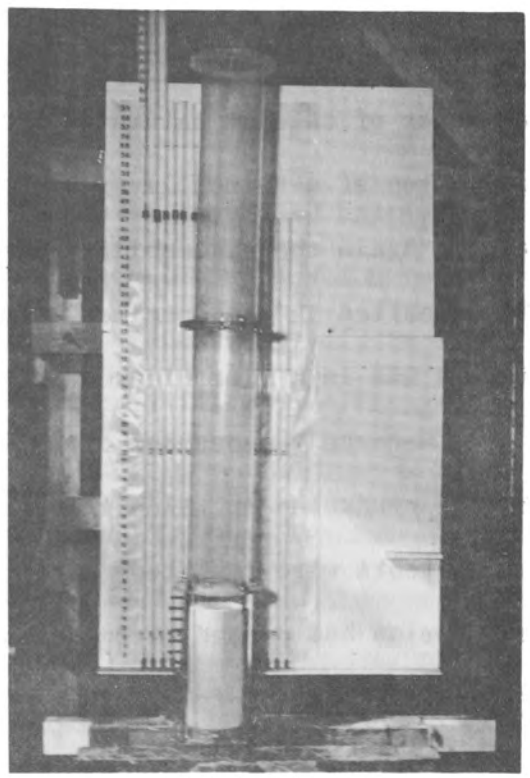
For the foregoing, the uniformity coefficient is defined as the ratio of the grain size for which 60 per cent of the particles are finer to the grain size for which 10 per cent are finer.

For these tests, suspensions containing 0.5, 1.0, 1.5 and 2.0 per cent bentonite by weight were used. After the sand specimen was placed in the permeameter and its initial permeability determined by conventional testing methods, the bentonite suspension was placed in a 4-foot high standpipe connected to the test cylinder and allowed to pass through the sand. Under these conditions, the hydraulic gradient was initially very high, gradually reducing to unity as the suspension passed through. In all runs, the suspension passed through the specimens freely without reducing their permeabilities. For the size range of sands tested, penetration would appear to be no problem; however, under the hydraulic gradients used, no sealing occurred. Plate 10 shows the permeameter setup for permeability testing and for injecting the bentonite using the standpipe.

Plate 10 Equipment for Penetration and Sealing Studies



Apparatus for determination of permeability of sand sample with clear water before sedimenting.



Apparatus for sedimenting phase of study with dispersed bentonite mixtures.

Tests with calcium -- In order to improve the opportunity for adhesion forces to be effective, efforts were made to supply calcium in the sand. The first step was to use a calcium carbonate sand described as follows:

> Salt Lake sand, median diameter 0.310 mm, uniformity coefficient 1.74 (Calcium Carbonate).

The Salt Lake sand was tested using the same procedure as for the chemically inert sands, with similar results. Since calcium carbonate is relatively insoluble, an attempt was made to increase the available calcium by treating the Barton sand with a saturated solution of calcium acetate. This left a coating of calcium acetate on each grain. Using the same technique, a 1 per cent bentonite suspension was passed through the specimen. Again no change in permeability resulted and no bentonite was retained within the sand.

In order to provide a still greater source of calcium, a 5-inch layer of calcium saturated zeolite, having similar grain size, was placed on top of a 5-inch layer of the Barton sand and the procedure repeated. Again the permeability was not affected, nor was any bentonite deposited in the specimen. In this instance, however, the effluent bentonite was in a flocculent condition.

Because the seepage drag might be expected to inhibit adhesion, tests were conducted in which this factor was reduced to zero. The last series of tests were repeated, except that after only a small amount of the suspension had passed through the column, the valve at the lower end was closed leaving a 2-foot column of the suspension above the zeolite layer standing for 24 hours. At the end of this time the valve was reopened. No water passed through the column and bentonite was found to have been deposited throughout the zeolite layer and the upper two inches of the sand layer.

A uniform mixture of one-half zeolite and one-half Barton sand was tested using the same technique as before, i.e., the flow of the bentonite suspension was stopped for 24 hours soon after passage through the column of material had started. Under these conditions the column was effectively sealed. Bentonite was found to have been deposited in the sand-zeolite material with the greatest amount in the upper two-thirds of the column.

As a check on the importance of the bentonite, the unmodified Barton sand was treated with a one per cent stable suspension in such a manner that the flow was stopped for 24 hours. In this case the treatment did not cause reduction of permeability and no bentonite was deposited in the sand.

Summarizing the results of the tests involving calcium, no difficulty was encountered in obtaining adequate penetration for the sands used in the tests under the range of hydraulic gradients used. Sealing of fairly coarse, clean sands occurred under conditions of high calcium availability and zero seepage velocity for a 24-hour period. Sealing did not occur in the Barton sand when calcium availability was zero even with zero hydraulic gradient for 24 hours. No limits were established regarding the minimum amount of available calcium necessary or the maximum seepage velocity permissible in order for sealing to occur in the various sands. Undoubtedly both of these limits would be related to pore size and it is conceivable that sealing may occur in materials with very small pores under conditions of very low calcium availability and fairly high hydraulic gradients.

Conclusions

For the size range of sands tested, full penetration was experienced under hydraulic gradients ranging from more than 4 to approximately 1. Sealing occured in these inert sands under conditions of high calcium availability and zero seepage velocity. It did not occur in even the finest sand with zero seepage velocity when no calcium was provided. Limits of calcium availability and seepage velocity under which sealing and penetration are possible for the various grain sizes were not fully established. In general, it would appear that penetration can be expected in soils having micropores in the size range tested even though they may be very high in calcium naturally, if large hydraulic gradients are used for the initial injection. After the injection is completed, one would infer that the hydraulic gradient should be reduced to the minimum possible in order to facilitate sealing. This could be achieved most practically by draining the pool at this time and eliminating the clear-water after-drive.

For coarse soils having low available calcium no penetration problem is anticipated. The picture with regard to effecting sealing is not entirely clear. In order to make the most effective use of the calcium that may be available naturally, one would infer that the sodium status of the initial suspension should be kept to the bare minimum necessary for stability.

Future Work

The relations of the factors of particle size, calcium availability, and hydraulic gradient or seepage velocity, to filtration, penetration, and sealing, have been only partly explored. Further work, using ideal soils or finer sand, needs to be done in order to delineate limits or ranges under which penetration or sealing can occur. These need to be extended to real soils. The work so far has considered only micropore penetration and sealing. For many field soils, the macropores may be much more significant than the micropores as far as seepage is concerned, and the work should be extended to cover such soils.

Mixing of Bentonite for Sedimenting Purposes

by Geo. E. Johnson,
The Central Nebraska Public Power and Irrigation District

The following excerpts are from a revised report on the above subject prepared by Mr. Geo. E. Johnson, C.N.P.P. and I.D., for the 1955 meeting at Scottsbluff, Nebraska of the 4-States Irrigation Council:

"During the past where bentonite has been used in connection with drilling of oil wells, the high pressure mud pumps available on the oil rig were generally used to mix the bentonite. If the initial mix was lumpy it could be re-circulated through the pumps until smooth. For sedimenting purposes it is difficult to re-circulate lumpy mixes. Therefore, in general a more complete initial job of mixing is required in the latter work than for most oil well drilling mud applications.

"In our work, we have also been governed by previous mixing experience and by the equipment on hand. Beginning in 1937, when we were constructing our power and irrigation project, we began mixing and pumping loess soil into cavities and around our structures to prevent seepage and settlement of the structures. During the period of 1937 to 1952 we mixed and pumped into the ground more than 500,000 cubic yards of loess soil in silt injection operations. We constructed the mixers and remodeled the pumps to fit this work, and this equipment was available at the time we began considering the use of bentonite for lining of our irrigation laterals and canals.

"When working with the bentonite in the laboratory, I found that the bentonite was much more difficult to mix with water than loess soil. I observed that with the laboratory high speed mixer it was difficult to produce uniform mixes. Excess mixing time was required. I recalled an experience during World War II in regard to the use of wheat flour in making alcohol at the Government plant which we constructed in Omaha. It was impossible for us to mix this flour in the regular mixing equipment that was used for ground corn; so we developed a jet similar to the jets we had been using to heat water with steam (enclosure 7). The problem was to get each grain of flour completely saturated before the grains could flock together into balls or lumps. I felt certain that the same type of mixer would work with the powdered bentonite.

"We calculated the amount of water required to give a 10 per cent bentonite mix at a rate of 300 pounds of dry bentonite per minute. The center 3-inch pipe was perforated by 110 $\frac{3}{32}$-inch holes, 1 inch apart, 30° angle with pipe, and all converging in the center of the pipe. The 6-inch pipe on the outside served as a jacket to give a uniform pressure on all of the holes. The outlet at the bottom of the 3-inch pipe was expanded to 4 inches so as to remove some of the pressure at the discharge end of the pipe.

"This jet will create approximately 15 inches of vacuum in the steel hopper set above the jet, and with the sliding gate perforated with a $\frac{3}{4}$-inch orifice, we were able to regulate the feed. However, it was necessary to place an electric vibrator on the side of the steel hopper in order to maintain a uniform feed of bentonite into the jet. To be certain that there were no lumps in the bentonite slurry from the jet mixer, a centrifugal pump was placed on the discharge line to produce further mixing.

"The slurry was discharged into one end of a long narrow holding pit where additional jetting could be utilized if necessary to complete the break-up of lumps. The slurry was pumped from the opposite end of the pit and into a diluting flow of water required to produce the sedimenting concentration.

"Experience with the jet mixer during the spring of 1954 and 1955 indicates that the bentonite slurry discharge into the holding pit will be free of lumps. During the 1955 installation a lumpy mix was initially produced, but after cleaning sand from the jet mixer an entirely satisfactory mix resulted.

"We have also tried other mixing methods. In trying to develop a mixer which could be used on small jobs, we tried the mixer on the Koehring Mudjack which has a rotary shaft with paddles running at high speed in a covered trough. Different sized pulleys were used to vary the speed and the pumps were disconnected so only the mixer was in use. Under all conditions, however, we found that this type of mixer would ball up and clog, resulting in unsatisfactory operation and mixture.

"The jet mixer in combination with supplemental pumping and a mud pit retention period of from 20 to 30 minutes has been the only method which we found that could satisfactorily mix large quantities of bentonite."

Additional mixing methods research is outlined under the following section on, "Procedures for Intermittently Operated Canals." No information on the Cronese Products Company research and method is available at this time.

Procedures for Intermittently Operated Canals

Many canals and laterals are relatively small. Many have relatively steep grades and widely spaced check structures. Some are operated, especially in water-short years, on a basis of three or less days per week. The above restrictions place limitations on the sedimenting procedures that can be used. Slow ponding procedures and the Johnson method of mixing cannot be used in many such instances. With these limitations in mind a limited amount of research work has been done on two small laterals near Colorado A and M College.

Little Cache Ditch Work

Three tons of bentonite were used in various tests involving the Lightnin mixer method of bentonite dispersion. The flow behavior of the various sedimenting charges in a test reach of lateral was observed.

A Mixco $1\frac{1}{2}$ HP mixer was mounted in a tank 40 inches deep and 28 inches in diameter with a 8" x 10" gate near the bottom. Water was pumped for the testing from Dry Creek, which is near the site. Two mix rates -- $\frac{1}{2}$ and 1 sack per minute -- were used. Both rates gave fairly satisfactory mixes but additional refinements in the method of adding the bentonite and in the tank design could probably produce entirely satisfactory results. Lack of financing has prevented completion of this work.

The mixtures produced in the mixing experiments were run into the Little Cache ditch. A Parshall flume was used for measuring the inflow of water into the test reach. A second Parshall flume located on the end of the ditch was used to measure the outflow of water from the last reach, which was about one mile long. The normal flow during the test runs was about 1 cfs. A total of about 2 tons of bentonite was used in the testing.

It seems unlikely that enough bentonite was used in the experimental work to do much sealing, but even though the ditch was cleaned this spring (1955), the farmers on the ditch claim that they can notice a definite reduction in losses. The losses at the start of the work ranged from 40 to 45 per cent. The testing during the summer of 1954 was cut short by water not being available, thus, the after losses could not be determined.

If financing can be found the flumes and the pump will be installed again this year so that a definite check on losses can be obtained. This needs to be done at a time when farm deliveries are not being made because there are no turn-out measuring devices.

<u>North Poudre Lateral No. 4 Work</u>

In an effort to develop a mixing method which could be accomplished entirely by irrigation district people and with normally available equipment, air jetting experiments were conducted in lateral 4 of the North Poudre Irrigation Company system. Seven tons of bentonite were placed in about a foot thick layer on the lateral bottom and just above a check structure. An air compressor was used to supply air to a $\frac{3}{4}$-inch jet pipe which was shoved into the partially wet bentonite layer. Jetting runs were made on August 14, 1954 and on October 12, 1954. The initial results were very favorable, but additional testing work is needed. Lack of financing has severely hampered this work.

Plate 11 Miscellaneous Mixing Methods

Mixing operation on Little Cache Ditch near Fort Collins, Colorado.

Mixing operation by air jetting into wet bentonite layer on lateral bottom, Lateral No. 4 near Wellington, Colorado.

While the primary purpose of the testing was concerned with mixing development work, water measurement records were also collected. Before the first mixing test the seepage loss in a mile test reach was about 50 per cent; after the first testing the losses were cut to about 20 per cent. This reduced loss was also noted during several of the intermittent irrigation runs which were made down the lateral later in the season. The inflow measuring device was a Parshall flume. The measuring devices on the farm turn-outs were two Parshall flumes and one rectangular weir.

Stabilizing Effect of Sedimenting Bentonite

by E. W. Lane and I. S. Dunn

The major emphasis of the present research and development work has been on the seepage reduction aspects of the sediment lining method. It has been realized that by depositing a sedimenting material, such as bentonite, in the pores of the canal bed and banks, stabilizing effects as well as seepage reduction effects could be obtained. The same void filling action that reduces the seepage should also have a cementing action on the bed particles and make them more resistant to scour.

This increased resistance to scour due to deposition of fine sediment in the interstices of the wetted canal materials frequently occurs naturally where the flow is increased gradually in a newly constructed canal. The process of bringing a canal gradually up to full discharge is called "seasoning." If canals must be put into action at full discharge immediately without seasoning, they must be designed to carry lower velocities than if they can be seasoned.

In certain areas the advantages of increased resistance to scour may be of greater importance than the reduction of seepage losses. Canals in fine materials like dune sand or loess are usually constructed to carry only a low velocity. Higher ones would cause undesirable scour. To carry the desired quantity of water at low velocities requires a larger and therefore more expensive canal than if high velocities could be used. In many cases therefore a satisfactory sedimenting treatment probably will provide not only a more water-tight canal but also a cheaper one.

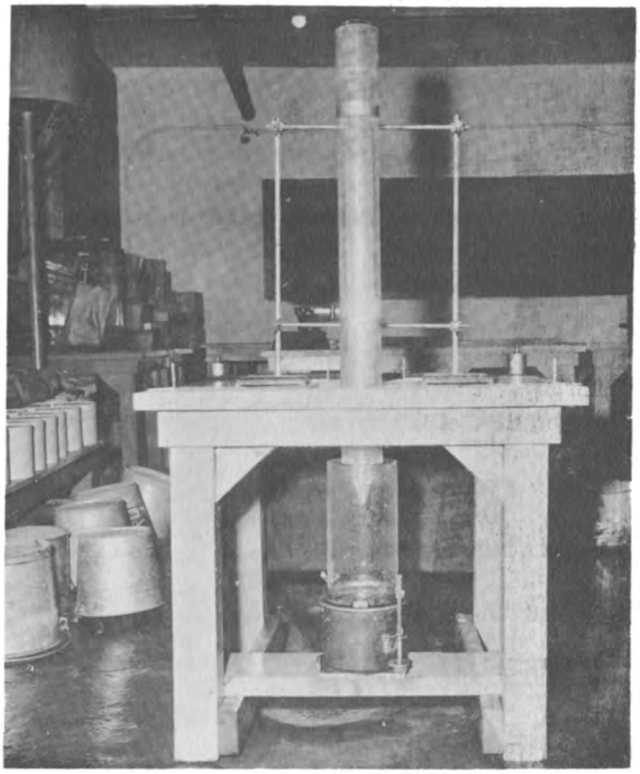
While studies are being conducted to determine the seepage reduction effect of the bentonite sedimenting treatment, the increase of resistance to scour should also be investigated. One way to make such a study is to measure the cohesion of the bank material before and after the bentonite sedimenting by means of an instrument known as the "vane borer". A study should also be made to determine the increase in allowable velocities in canals with the increase in cohesion of the bank materials shown by the vane borer tests. From the results of these studies it may be possible to design smaller canals through sedimenting treatment to take advantage of the smaller costs of construction.

Within the limits of the available financing, work has been started at Colorado A and M College to construct and calibrate a vane borer for the testing outlined above.

Any increase in resistance to scour of the canal bed after bentonite sedimenting will probably be produced by the cohesive action of the fine colloidal clay particles. This cohesive action should cause an increase in the shearing strength of the bed. The change in strength can be measured by means of a shear apparatus called the "vane borer" mentioned above. This instrument will measure the shearing strength (cohesion) of the surface layer of the bed "in situ".

The relation between cohesion and resistance to scour can be investigated in the laboratory by hydraulic shear tests on samples of soil with various degrees of cohesion. The hydraulic shear can be produced by a vertical jet of water with controlled velocity impinging on the surface of the sample. The velocity of the jet is increased until

Plate 12 Equipment for Stabilization Studies



Vertical jet apparatus for measuring hydraulic shear.

Vane Borer apparatus for determining cohesion.

scour is produced on the surface. Hydraulic shear and cohesion may then be compared in graphical form. Studies of the above relationship will be conducted during the summer of 1955. It is planned, after the laboratory tests, to make observations in operating canals to determine the relation of the permissible velocities in canals in natural cohesive material to the shear values measured by the vane borer.

Effect of Sedimenting Bentonite on Irrigated Land

Research on this effect was originally planned but it was deferred for the following reasons:

1. Initial sedimenting experience indicates that all of the bentonite is used up in the lateral being treated.
2. The amount of bentonite that subsequently can be picked up during normal irrigation water deliveries seems to be negligible. A normally muddy irrigation water commonly contains more clay.
3. Studies on this effect may be started at a later date, but for the present the limited available financing is being concentrated on research and development of the actual method. Studies of the side effects of the method, which as yet is not fully defined or developed, would be premature at this time.

Chapter VII

CONCLUSIONS

Based on the initial research and development work on the bentonite sediment lining method, including both field and laboratory results, some general procedure statements can be made. It will be realized, however, that each project area and pervious material present individual problems that usually will require some modification of the sedimenting procedure. The experimental procedures used in the initial cooperative installations produced sealing results that were (1) very favorable for the Tri-County installation in loessial soils, (2) generally favorable for the North Platte Project installation in dune sands, and (3) slightly favorable for the Kendrick installation in fractured shale. In all three installations, the need for additional research and development of the installation and evaluation methods was evident. For this reason the following conclusions relating to sedimenting procedures and evaluations also include references to research and development problems. The procedure and evaluation conclusions are discussed in their normal chronological order.

Before and after sedimenting record -- Direct measurements of water losses by ponding before and after the sedimenting work, supplemented by some flow measurements, seem to be absolutely necessary in order to achieve any quantitative evaluation of an installation. Only by these methods can a reliable estimate of water losses be made. Where the water losses are producing damage in nearby lands, detailed water table and seeped area maps before and after the sedimenting are also required. This type of information is needed so that a benefits-to-costs comparison can be made.

Preliminary testing -- Some phases of the preliminary testing work, such as the dispersion tests, can be performed in the laboratory. Field application, however, involves many important variables that cannot be duplicated readily in the laboratory. These include existing soil structure, natural sediment cakes, crayfish holes, depth to water table, salt status of soils and ground water, and canal operating conditions. Thus, in many instances most of the preliminary procedure development testing must be conducted at the field site. By restricting the initial work to a small section of lateral, which is a representative part of the over-all canal system, the field variables may be taken into account economically.

Presedimenting condition of lateral -- It was assumed that it would be best to run the sedimenting mixtures into the dry channel just before the start of the irrigation season because (1) cracking resulting from drying and frost action would provide entry through the natural sediment cake, and (2) the ground water table and the soil moisture would normally be at the lowest stage, hence, the effective sedimenting head would be at a maximum. No evidence has been observed that indicates the contrary, therefore running the sedimenting suspension into a dry canal is recommended.

High-swell bentonite compared with local clay -- The initial work has been performed in areas relatively close to the high-swell bentonite processing plants. If the sediment lining work spreads to areas more distant from the high-swell bentonite deposits, it may be advantageous to utilize local clays, but the problems of mining, maintaining uniformity, chemical beneficiation and eliminating the over-size particles should be fully considered. Different mixing methods, probably similar to those used in the Tri-County Project silt injection work (11), might be required.

Hard water problem -- Since most irrigation waters are hard, some flocculation of dispersed clay colloids will occur. If a slow ponding procedure of sedimenting is employed flocculation and settling must be controlled. This usually can be achieved by using chemical dispersants, which reduce the flocculent effect of calcium and magnesium in addition to reducing the viscosity of the bentonite slurries. The amount and kind of dispersant necessary depends on the water and on the clay colloid being used.

Mixing problem -- Stable dispersions of clay colloids depend not only on chemical conditions but also on the completeness of the mechanical dispersing effect. Producing large quantities of uniform, lump-free, and stable dispersions of powdered bentonite is a difficult and troublesome problem when inadequate equipment is used. The Johnson multiple-jet device used in the Tri-County work does a good job of mixing. The mixing cost on the Tri-County work was about $10.00 per ton as compared to the average cost of about $30.00 per ton on the other two installations where the mixing was accomplished by contractors using the single jet method. The latter method is commonly utilized in mixing drilling muds.

Mud pit cycle -- A mud pit cycle between the mixing process and the addition into the lateral being treated is recommended because it provides (1) a control so that lumpy unsatisfactory mixes can be supplementally mixed by additional water or air jetting; (2) extra time for "curing" or complete hydration of the clay colloid; and (3) a stand-by volume and better control for slurry additions into the diluting flow of water in the lateral. For the convenience of jetting a long narrow pit is preferred. The pit volume should be sufficient to provide a slurry retention time of at least thirty minutes.

Sedimenting concentration -- In the initial sedimenting work in which slow ponding procedures and high-swell bentonite sediments were used, the concentration was limited to a minimum of one per cent because the mixture tended to flocculate at a lower concentration and to a maximum of two per cent because of cost considerations. Actually it is risky to generalize on the concentration required since it should be tailored to fit the canal site conditions of pervious materials, water, and operating conditions. Where possible the sedimenting concentration and duration of ponding should be determined by prior laboratory and field testing.

Ponding phase of sedimenting -- The major problem during the critical ponding phase is to produce conditions conducive to bentonite penetration and sealing-in-depth. Where spacing of check structures and canal grade permit, the slow ponding procedure is recommended. In the pervious materials tested, this procedure seems to produce a good penetration and sealing action because (1) ponding depths are slowly built-up, (2) movement of bed-load sediments is virtually eliminated, and (3) the non-colloidal fraction, which hinders penetration, is rapidly eliminated by settling.

Slow ponding procedure -- This water running sequence has normally consisted of ponding the suspension behind the first check structure in each test section of channel. Depending on the mix rate and volume of the first pond, this may take from one to three days, or longer. After the first pond is filled, the bentonitic water is released preferably from under the check planks, but at a rate equal to the inflow so that a uniform pond level is maintained in the first pond. The procedure is repeated down the channel being sedimented. Upon completion of the mixing, an after-drive of clear water is continued so that uniform pond levels can be maintained at the same high elevations until normal irrigation deliveries are begun. This full depth-low velocity condition should give the bentonite ample time to penetrate. The after-drive of clear water introduces some additional difficulties to the process. It is possible that it may be eliminated and this point will be given further study.

Overrun problem -- The clear water after-drive, instead of staying behind the bentonite suspension slug, has shown a definite tendency to overrun the sedimenting water. This produces problems of dilution. The introduction of new chemical ions causes flocculation and settling problems. There are apparently two ways to improve this: (1) softening the after-drive of clear water, and (2) increasing the initial concentration of the sedimenting charge. Actually in the case of loessial soils, the flocculation tendency of the diluted sedimenting water may have helped the sealing action. This point, however, needs more research.

Penetration and sealing -- During slow ponding procedures involving the transportation of a bentonite sealing material, a sodium environment seems most favorable. With respect to retaining the bentonite colloid in the pores of the pervious canal bed-materials tested, there is evidence that a calcium environment, or at least one dominated by a multivalent cation, is best. While a sodium water may have some beneficial effect by causing dispersion of the clay fractions of the site soils, this would be a secondary effect since the primary objective of the treatment is to inject the new colloids into the pores and macropores of the site materials. In permeable clayey soils, however, the sediment lining method of injecting the dispersing agent alone may provide an effective and economical sealing. In very pervious materials, where penetration is no problem, the sediment sealing action probably would be enhanced by the presence of coarser sediment particles which would act as bridging agents.

Depth of penetration -- If the pervious soils possess a natural bentonite content, and many of them do, evaluation of penetration is complicated because the new bentonite cannot be distinguished from the natural by the benzidine test. It was thought that the sodium-zinc uranyl acetate test might be helpful because this depends on a reaction involving exchangeable sodium. However, the exchange reactions make this method equally uncertain. Thus, direct measurements of penetration in the field have been virtually unobtainable but indirect indications are that penetrations to depths of 1 foot and more has been achieved in instances where installation conditions were fairly favorable.

Costs -- In the initial experimental work, the costs have ranged from about 7 cents to 30 cents per square yard. The higher extreme in cost is attributed to experimental procedure problems and an abnormally high cost for mixing, the lower extreme in cost may be improved still by promoting efficiency of material handling and sedimenting procedures.

Chapter VIII

RECOMMENDATIONS

1. There are indications that sedimenting materials other than bentonite may be required to seal adequately some types of pervious materials. The extremes of permeability, the slightly pervious and the extremely pervious, appear to present the most difficult problems for the bentonite sedimenting method. The bulk of the pervious materials, however, are between the two extremes. For the present, therefore, it is recommended that the sediment lining project work remain concentrated on: (1) the use of colloidal clay sediments, and (2) the sedimenting of loess, sands, and fractured bedrock.

2. To avoid the evaluation problems of the 1954 experimental installations, the following order and timing of future work is recommended:

   a. Systematically sample, evaluate, and describe the pervious canal bed-materials before sedimenting.

   b. Determine "before-lining" seepage losses by both ponding and flow measurements, preferably for one full season ahead of the sedimenting. Area of seeped land measurements should also be included if necessary.

   c. Evaluate and develop the sedimenting research methods and materials to be used in the field site installations. Laboratory testing would be utilized to the fullest practical extent.

d. Install the experimental sediment lining, probably at the beginning of the irrigation season following the seepage loss determinations.

e. Determine "after-lining" seepage losses and areas, and collect "after-lining" canal bed samples for penetration and sealing evaluations. The same methods as in a , b , and c above would be used and repeated 2nd and 3rd years if needed.

3. To accomplish the specialized research, development, and evaluation work outlined above and to obtain a clear understanding of the basic sediment lining principles involved, a three way cooperative program is proposed. The following program provides for an integration of efforts of a research team of sediment lining specialists, irrigation organizations, and private industry.

a. Research team -- The over-all objectives of this team would be to (1) arrive at an understanding of basic principles involved in the sediment lining method, (2) develop methods of applying this under practical conditions, and (3) report these in such a way that operation and construction engineers may use them. It is believed that the initial sediment lining results and the magnitude of the canal seepage problem constitute ample justification for the following research and development team:

(1) Project leader -- general supervision.

(2) Irrigation engineer -- assistant to project leader, and technical reports writer and co-ordinator.

(3) Hydraulic engineer -- responsible for "before and after" measurements of canal seepage and for ponding phases of experimental sediment lining installations (including laboratory hydraulic model development work if required).

(4) Soils engineer -- responsible for preliminary testing involving site soils, water and sedimenting material, and for "before and after" evaluations of sediment sealing effects in pervious canal bed soils.

(5) Equipment foreman -- responsible for testing of bentonite mixing methods and for mixing phases of experimental installations -- qualified for "trouble-shooter" work on mixing equipment problems.

b. Cooperation from irrigation industry -- Since the major objective of the sediment lining research is to develop a dependable and effective canal lining method it seems logical to conduct the maximum possible amount of the research and development work in operating canals or laterals and in cooperation with interested irrigation districts. Since the research team would perform the preliminary research and development work for several representative field site installations, it is proposed that the local irrigation district involved install these experimental linings and pay for the materials and mixing.

c. Cooperation from private industry -- Since the development of the sediment lining method would benefit private industry, such as bentonite, chemical, and mixing companies, their continued support to the sediment lining program seems warranted. It is proposed that they continue their support of the fundamental phases of the sediment lining research at Colorado A and M College. This research would be coordinated and supervised by the appropriate research team members and it would also include the College phases of the present cooperative work with the U. S. Geological Survey. Help on materials and mixing for experimental installations probably would also be solicited.

4. The proposed cooperative research and development approach seems to have several advantages. Probably of primary importance are the practical experience and knowledge of local irrigation operations personnel, whose cooperation will assist in the development of sedimenting procedures that are both practical and adaptable to local conditions. In addition, information obtained from the comprehensive evaluation of field site conditions offers a convenient and practical way to restrict sedimenting variables of soil, water, and sediment, especially in the fundamental phases of the research and development work that can be conducted

in the laboratory. In the follow-up phases of the cooperative research work, including the installation work, valuable irrigation water can be saved and training of local operating personnel can be accomplished. It is therefore believed that much can be gained by the close integration of fundamental and experimental field installation phases of the research and development work for the sediment lining method.

Proposed Budget and Organization

The following three way cooperative program is proposed as a long-range goal of organization and financing:

1. Research team -- Organization of the following research team with a reasonable assurance of stable financing over a minimum period of five years.

Budget Item	Per Annum
Project Leader (Federal GS-12 level)	$ 7,040.00
Irrig. Engr. and Assist. Proj. Leader (GS-11 level)	5,940.00
Hydraulic Engineer (GS-11 level)	5,940.00
Soil Chemist (GS-11 level)	5,940.00
Equipment Foreman (GS-11 level)	5,940.00
Equipment (laboratory, office, automobile, etc.)	14,500.00
Operating expenses (laboratory and office)	24,700.00
Travel	5,000.00
Total Per Annum	$75,000.00

2. Field installations -- It is proposed that the cooperating irrigation projects pay for the installation costs. Possibly industry may help by donations of materials or equipment. The cost of the field installations is estimated as follows:

Budget Item	Per Annum
Assume three installations per year	$30,000.00
Total Per Annum	$30,000.00

3. Industry support -- It is assumed that Industry support of the College Fellowship Program and the U.S.G.S. cooperative work on sediment lining research will continue -- estimated as follows:

Fellowships (3 at $\frac{1}{2}$ time -- $1800 each plus $700.00 expenses)	$ 7,500.00
Cooperative program with U. S. Geological	4,500.00
Survey matched by Federal Funds	4,500.00
Total Per Annum	$16,500.00
Total Annual Program	$121,500.00

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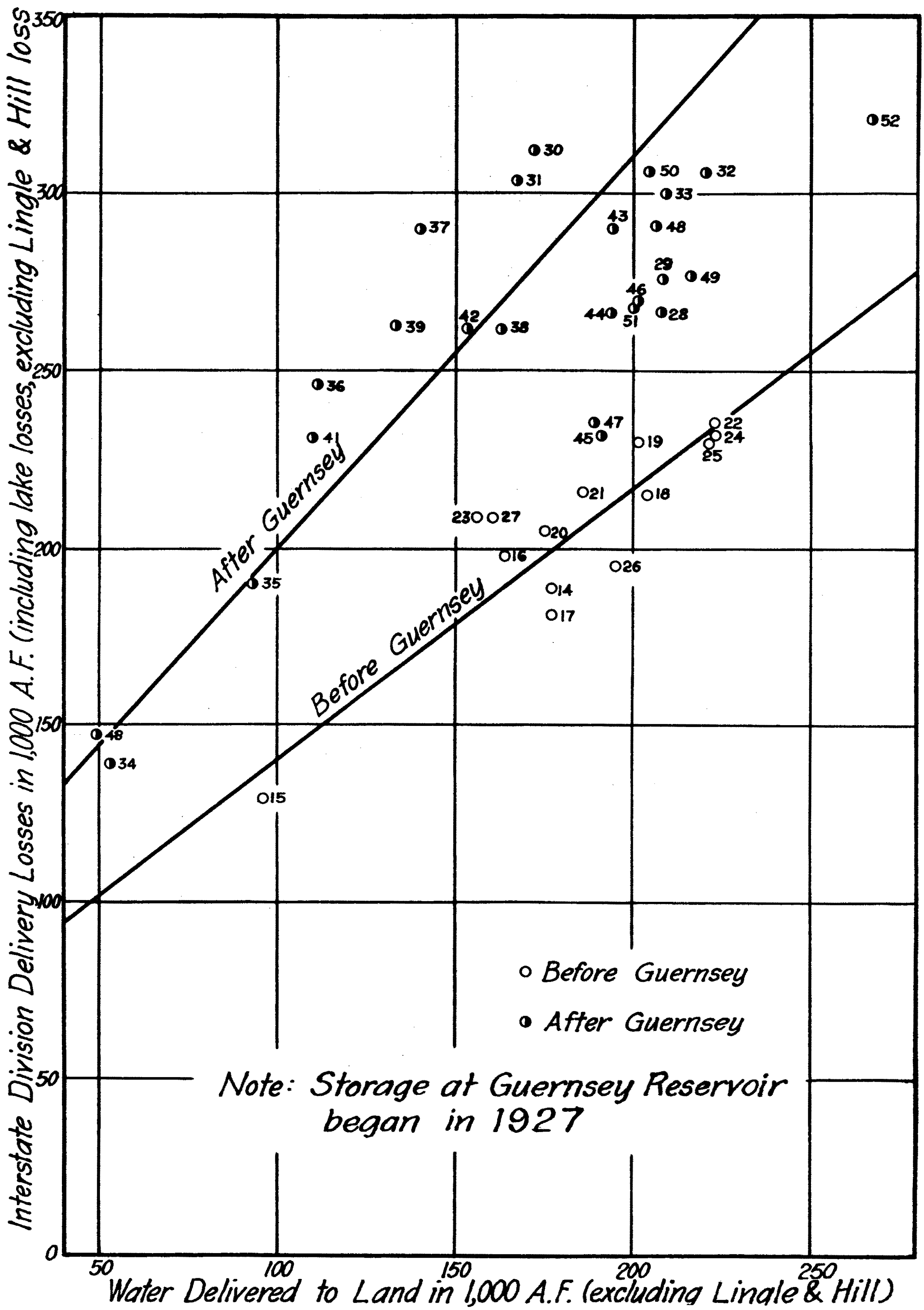
A P P E N D I X

APPENDIX

TABLE OF CONTENTS

Enclosure 1



Interstate Division Delivery Losses in 1,000 A.F. (including lake losses, excluding Lingle & Hill loss)
Water Delivered to Land in 1,000 A.F. (excluding Lingle & Hill)
After Guernsey
Before Guernsey
○ Before Guernsey
◑ After Guernsey
Note: Storage at Guernsey Reservoir began in 1927

Enclosure 2

Results of Laboratory Testing
Lateral 218 -- Kendrick Project -- Wyoming

	Sample Sta[1]	Clear Water Before[2]	2 per cent Bentonite[2]	Clear Water After[2]
Lat. 218	85 + 00	34 min	10 hrs	3 hrs 10 min
	98 + 00	16 min	1 hr	35 min
	104 + 00	16 min	2 hrs	1 hr 8 min
	126 + 00	12 min	2 hrs 15 min	1 hr 24 min
	137 + 00	15 min	2 hrs 30 min	1 hr 57 min
	354 + 00	12 min	2 hrs 35 min	1 hr 35 min
	end	6 min	1 hr 30 min	37 min
Lat. 218-10	15 + 25	19 min	22 hrs	1 hr 45 min
	29 + 00	17 min	6 hrs 25 min	1 hr 15 min
	44 + 00	11 min	16 hrs	1 hr 45 min
	49 + 00	10 min	3 hrs 45 min	1 hr 5 min
	66 + 00	29 min	17 hrs	3 hrs 20 min

[1] All samples were silt with varying amounts of clay and sand, except for sample from end of lateral, which was a dune sand.

[2] Samples were compacted into large size juice can ($4\frac{1}{2}$ in. diameter 7 in. high with perforated bottom). Two-inch space left for water on top of each sample. Times shown are for two-inch drop in water level from top of can to sample. "After" tests were run after bentonite cake was removed from surface of sample. Testing was accomplished during winter of 1952-1953.

Enclosure 3

Summary of Mixing and Ponding Data
Lateral 218 -- Kendrick Project -- Wyoming

Mixing period -- Started 6:00 a.m., May 6, 1953 -- ended 2:00 p.m., May 7, 1953. A few delays in delivery of bentonite caused some gaps in the mixing. Total mix time -- 29.22 hours.

Mix point location -- Station 2 + 60 at head weir in lateral 218.

Mixing equipment -- Single jet hopper mixer used by contractor -- Halliburton Oil Well Cementing Company. Pumps to supply jet -- truck-mounted.

Mix water source -- From head weir pond -- 0 + 00 to 2 + 56.

Total bentonite -- 75 tons or 1500 sacks.

Total dispersant -- None -- need for dispersant not recognized in this early work.

Mix rate -- Varied from 2.5 tons/hr to 2.9 tons/hr into an average flow of mix water of about 168 gpm.

Slurry concentration -- varied from 6.0 per cent to 6.9 per cent of bentonite to water (by wt.) -- mix seldom free of lumps. Slurry was discharged from jet hopper directly into turbulent water spilling over head weir.

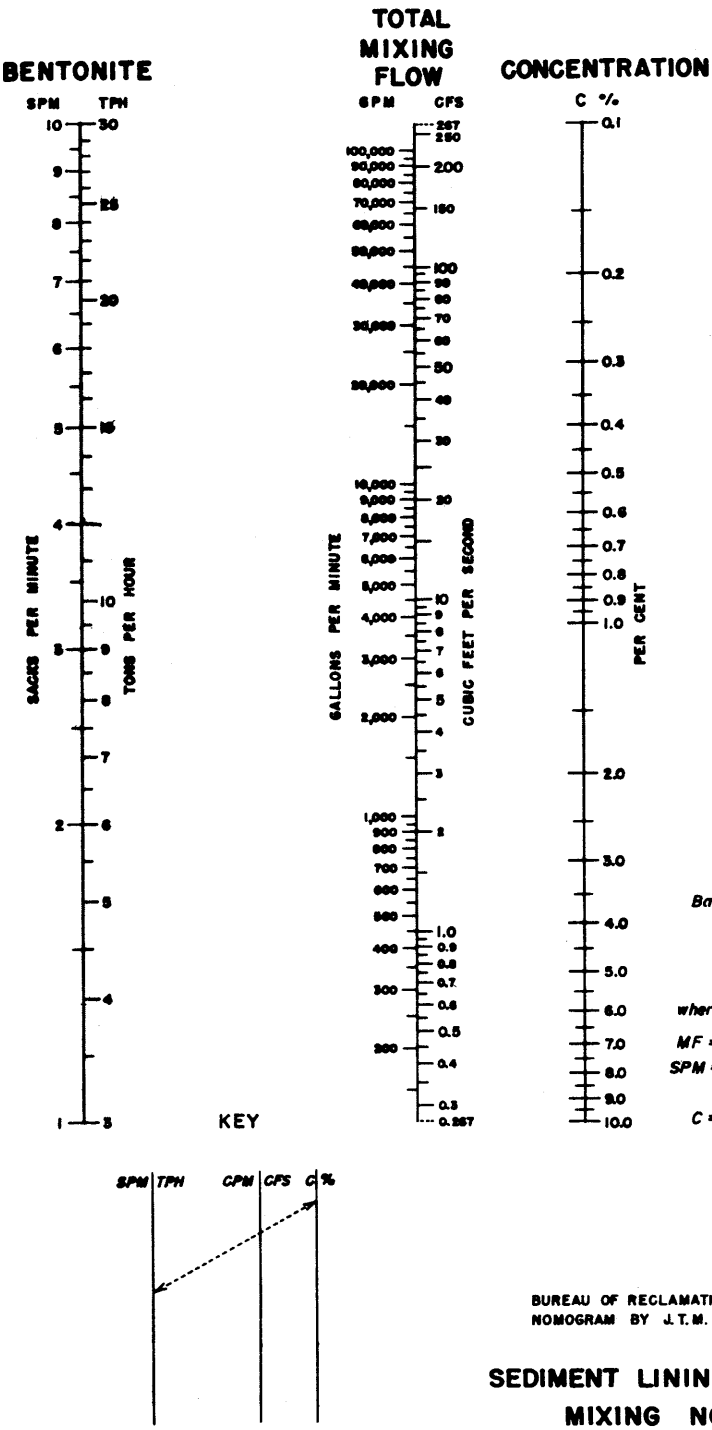
Diluted concentration -- Diluting flow over head weir varied from 1.0 to 2.0 cfs -- regulated from head-gate for lateral. Final concentration varied from 1.0 per cent to 1.6 per cent.

Total volume of sedimenting charge -- 3.68 acre-feet.

Canal bed conditions -- Fairly dry just before sedimenting started. All check boards in existing check structures -- some temporary checks put in at drop structures.

Water running procedure -- Sedimenting water ponded as high as possible in each checked reach of canal. A clear water drive following the sedimenting was not utilized; thus, canal bottom was allowed to dry out for several weeks until the normal run of irrigation water was begun.

Enclosure 4



Based on the formula:

$$MF = \frac{SPM \times 2.67}{C}$$

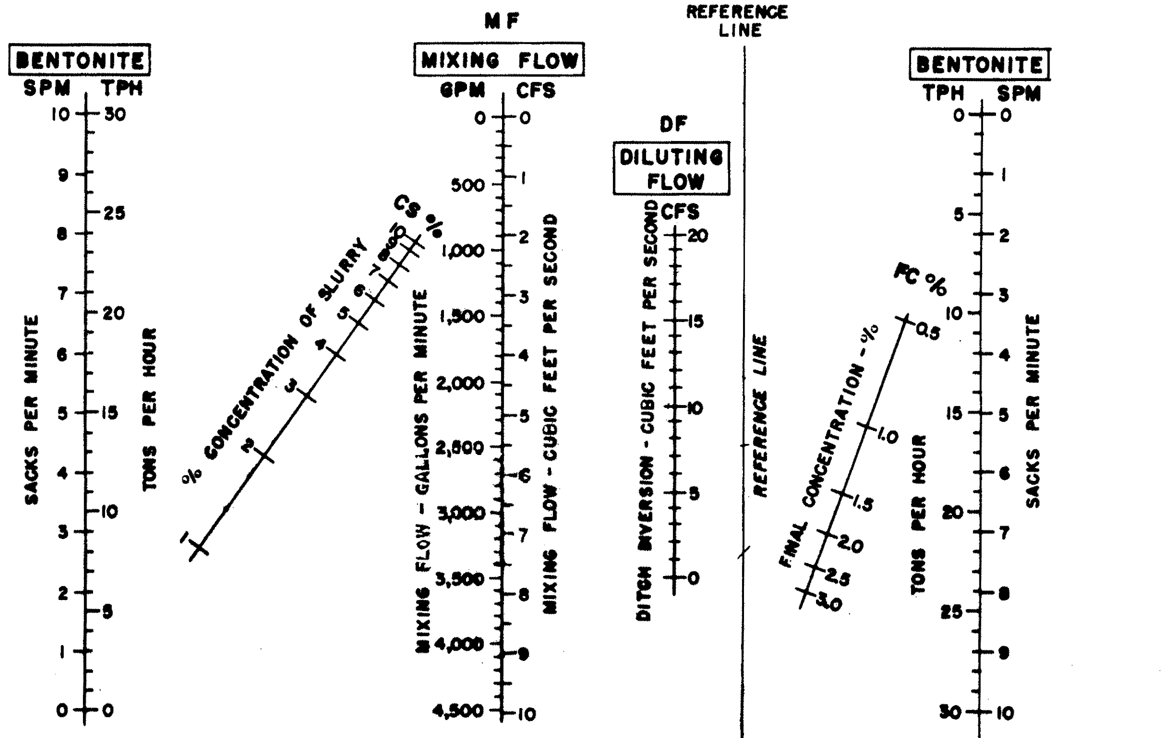
where

MF = mixing flow (CFS)
SPM = 100 lb sacks of bentonite per minute.
C = Concentration per cent by weight

BUREAU OF RECLAMATION — REGION 7
NOMOGRAM BY J.T.M. DRAFTED BY W.A.F.

SEDIMENT LINING SINGLE-STAGE MIXING NOMOGRAM

Enclosure 5



Based on formula:

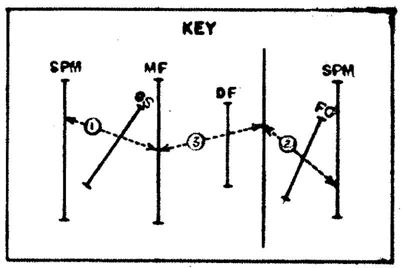
$$FC = \frac{SPM \times CS \times MF}{SPM\ (MF + DF)}$$

Where:

FC = final concentration % by weight.
SPM = 100 lb sacks of bentonite per minute
CS = concentration of slurry % by weight
MF = mixing flow (cubic feet per second)
DF = diluting flow (cubic feet per second)

Under the condition:

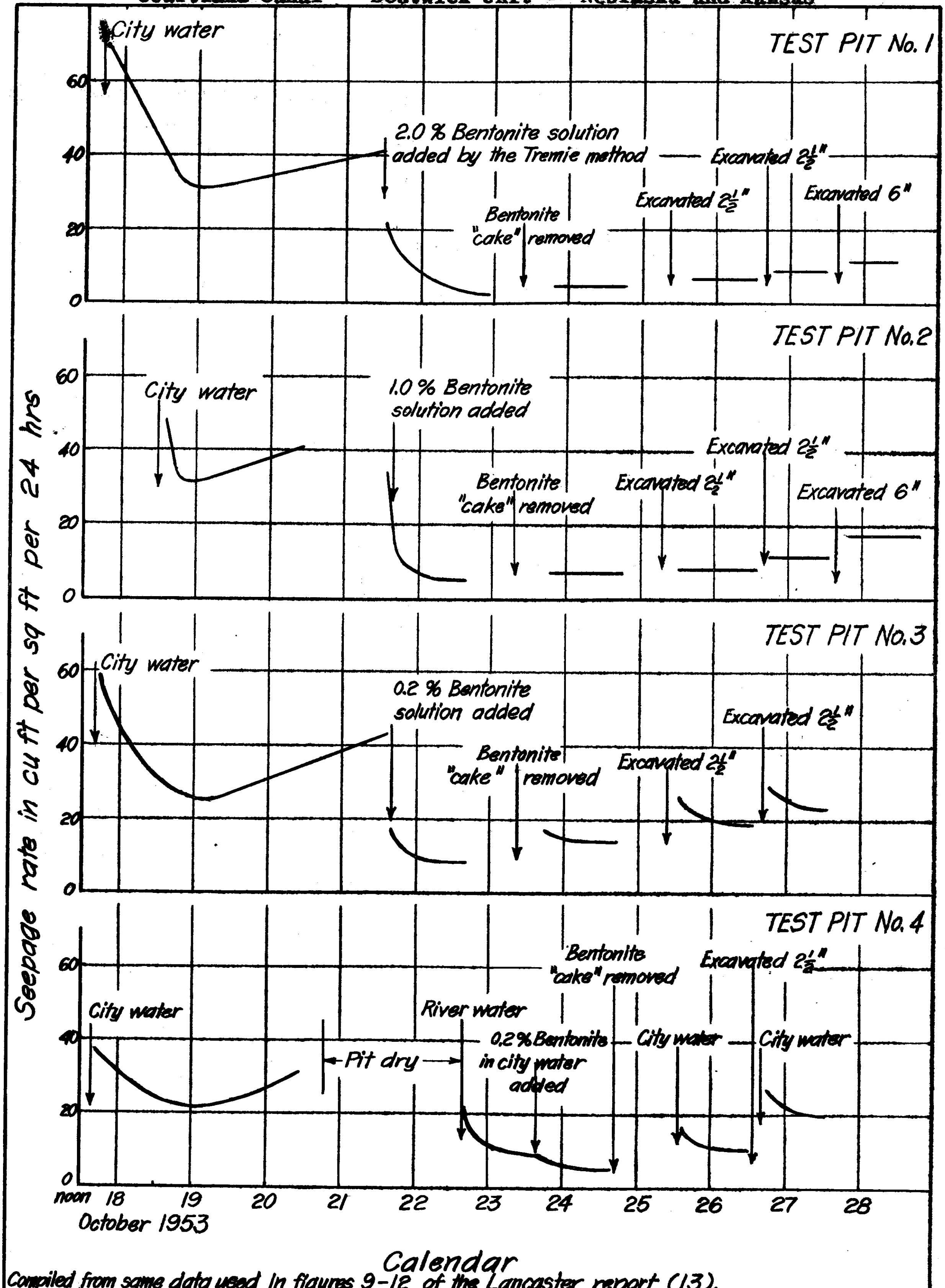
$$CS = 2.67\left(\frac{SPM}{MF}\right)$$



SEDIMENT LINING TWO-STAGE MIXING NOMOGRAM

BUREAU OF RECLAMATION —— REGION 7
NOMOGRAM BY J.T.M. - DRAFTED BY W.A.F.

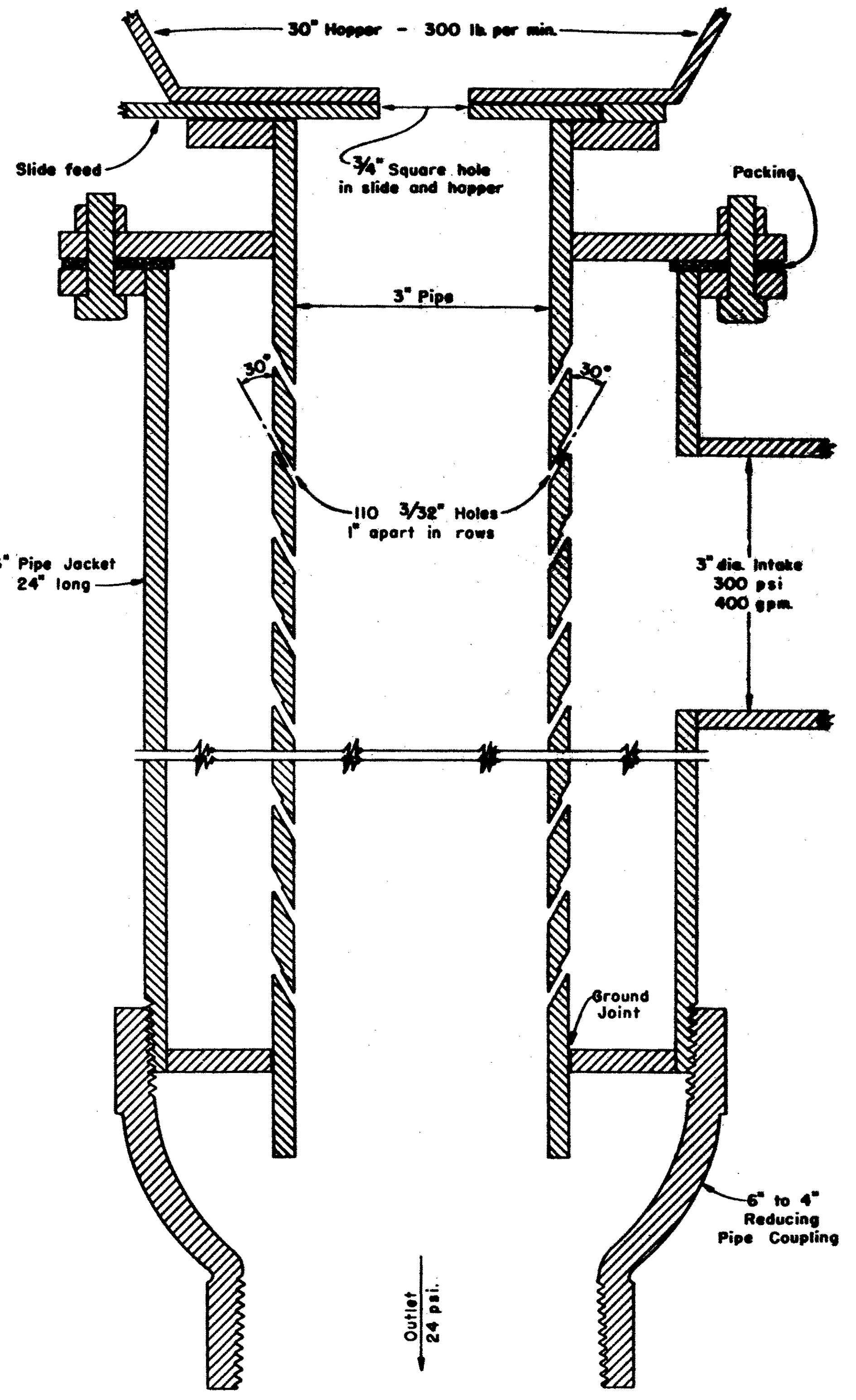
Enclosure 6 Results of Feasibility Tests in Loessial Materials
Courtland Canal -- Bostwick Unit -- Nebraska and Kansas



Compiled from same data used in figures 9-12 of the Lancaster report (13).

Enclosure 7

THE CENTRAL NEBRASKA PUBLIC POWER AND IRRIGATION DISTRICT



JET MIXER
FOR BENTONITE

Geo E Johnson
Chief Engineer

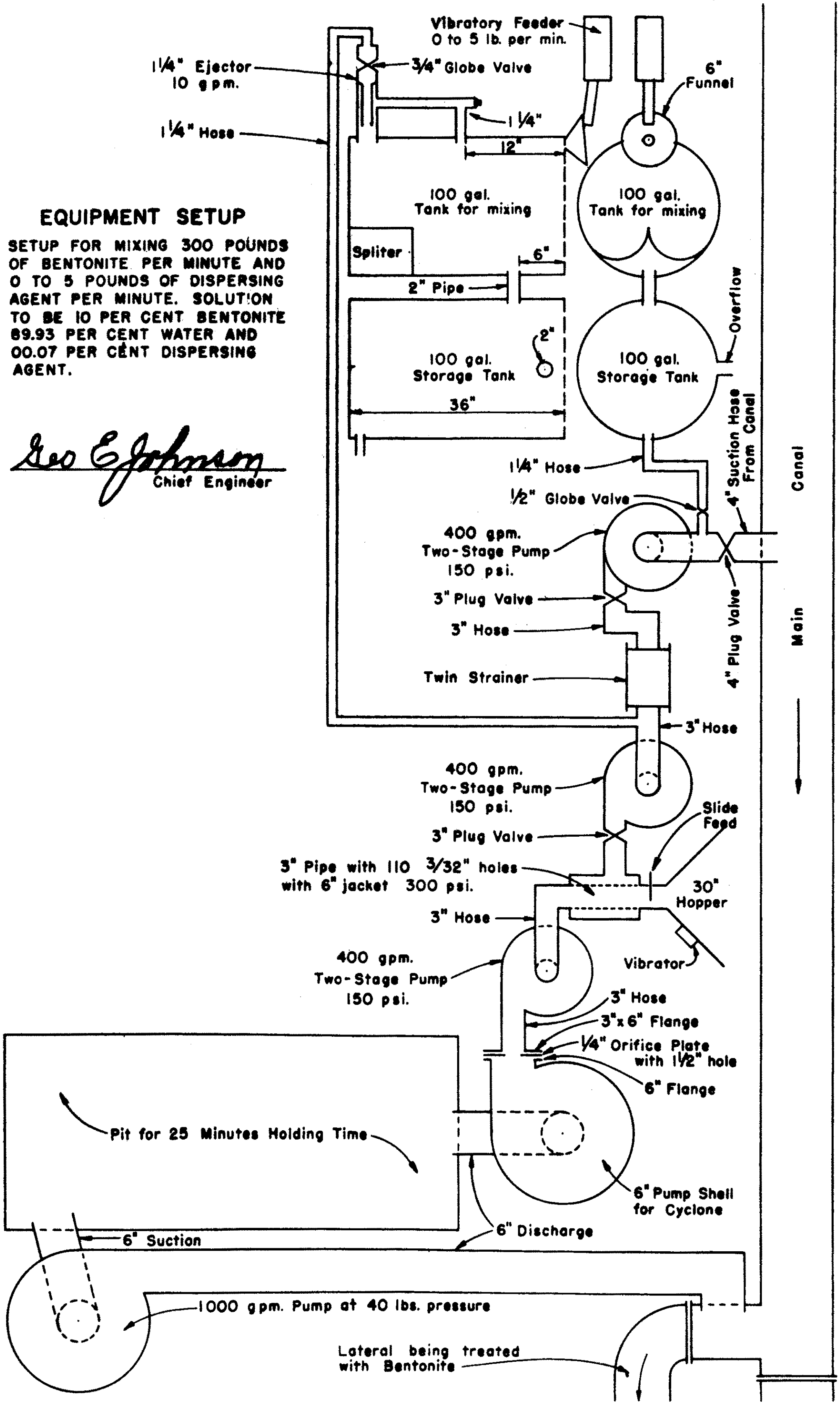
Enclosure 8

THE CENTRAL NEBRASKA PUBLIC POWER AND IRRIGATION DISTRICT

EQUIPMENT SETUP

SETUP FOR MIXING 300 POUNDS OF BENTONITE PER MINUTE AND 0 TO 5 POUNDS OF DISPERSING AGENT PER MINUTE. SOLUTION TO BE 10 PER CENT BENTONITE 89.93 PER CENT WATER AND 00.07 PER CENT DISPERSING AGENT.

Geo E Johnson
Chief Engineer



Enclosure 9

Summary of Mixing and Ponding Data
Lateral 19.3 -- E-65 Main Lateral -- Tri County Project -- Nebraska

Mixing period -- Started 1:35 p.m., February 9, 1954 -- ended 9:45 p.m., same day. Some gaps in mixing at beginning -- total mix time -- 7 hours 45 minutes.

Mix point location -- On south bank of E-65 main lateral at turn-out for 19.3 lateral. Approximately 3 miles west and 3 miles north of Bertrand, Nebraska.

Mix water source -- Ponded reach of E-65 main lateral above check-drop structure at Mile 19.3 -- normal irrigation water used.

Total bentonite -- 26.6 tons or 532 sacks of powdered, high-swell from Benton Clay Company.

Total dispersant -- None.

Mix rate -- About 100 pounds per minute into 200 gpm of ditch water.

Slurry concentration -- About 6 to 8 per cent bentonite (to wt. of water)

Diluted concentration -- Slurry discharged directly into gate opening for lateral 19.3. Gate adjusted so final mix was about 0.5 per cent bentonite. Total sedimenting flow around 5 cfs. Mixing continued until 2700-foot section filled -- 1 foot above normal.

Lateral capacity and condition -- Initial design capacity -- 26 cfs. Lateral bottom at beginning of sedimenting was partially covered by water, snow, and weeds.

Sedimenting procedure -- Ponded bentonite water not run beyond first ponded section -- allowed to soak into lateral bottom and evaporate.

Mixture stability -- Bentonite mixture was unstable. Flocculated -- clear water showing on top on second day.

Sealing effect -- Seepage rate after sedimenting reduced to 42 per cent of original ponding test rate.

Enclosure 10

Volume of Ponds
Tri-County B-65 Installation

Section	Ponding Structures	Approx Volume[1] cu ft	Approx Wetted Area[2] sq yd
1	Mile 23.7 to Mile 24.6	270,000	13,500
2	" 24.6 " " 26.0	470,000	23,400
3	" 26.0 " " 27.9	620,000	30,900
4	" 27.9 " " 28.7	246,000	12,300
5	" 28.7 " " 31.3	830,000	41,400
6	" 31.3 " " 32.8	515,000	25,800
7	" 32.8 " " 35.5	835,000	41,700
8	" 35.5 " " 36.2	210,000	10,500
Total Miles	12.5	Total 3,996,000	Total 199,500

[1] With water level about 1 foot above normal at lower end.

[2] Wetted canal perimeter area.

Note: Assume that the volume per mile of canal is 320,000 cu ft and that a 30 per cent shrink per mile (or equal to drop in pond level of about 1.5 feet of average 5.0-foot depth) will take place, then the shrink per mile would be 96,000 x 12.5 or 1,200,000 cu ft. Add a safety factor of 100,000 cu ft gives 1,300,000 cu ft. At 1 per cent concentration, about 400 tons of bentonite were required.

Enclosure 11

Summary of Bentonite Dispersion Tests[1]
Tri-County Project Installation

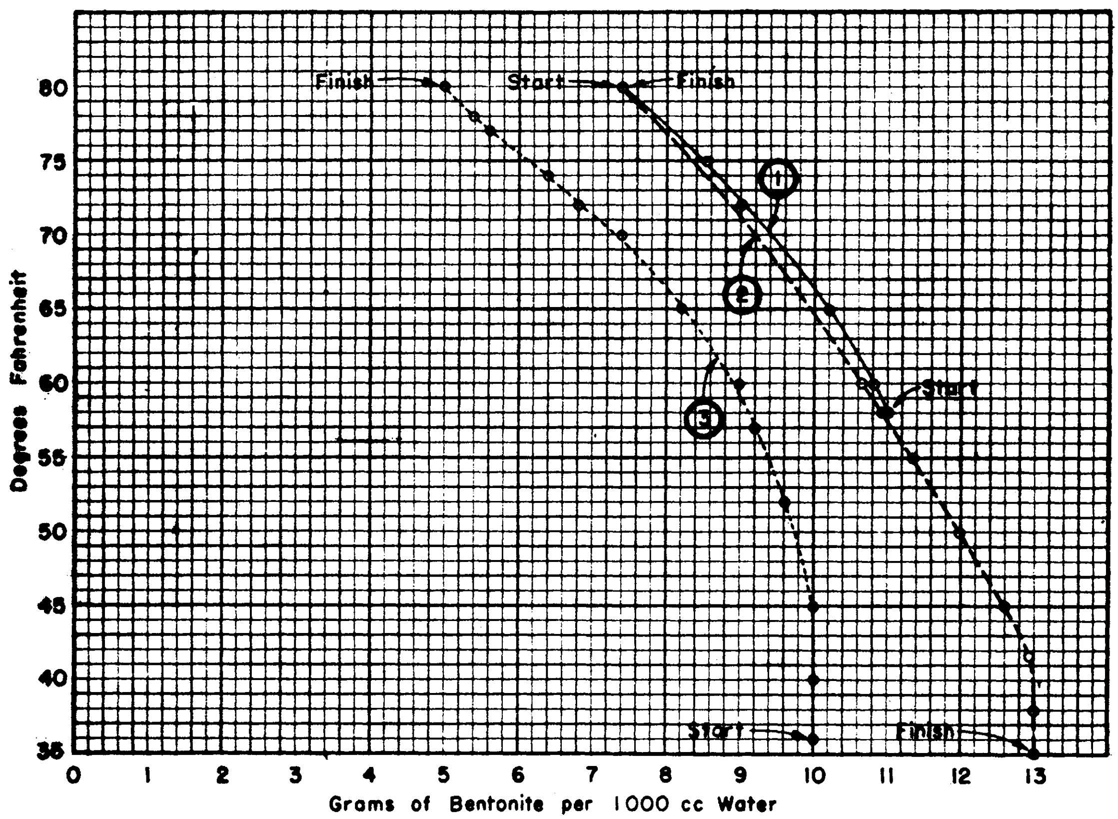
Test No	Bentonite[3]	Dispersant gms[4]		Initial	24 hrs	end[5]	Remarks[6]
	Trial Mixes[2]			Hydrometer Readings After			
1	10.0	.05	TSP	7.2	5.0	5.2 (7)	Nearly uniform color
2	10.0	.05	STP	7.2	5.0	5.0 (7)	" " "
3	10.0	.05	SHP	7.2	5.0	5.2 (7)	" " "
4	10.0	None		6.6	4.2	2.0 (7)	Bottom 1/3 darker, top cloudy
5	7.5	.05	TSP	4.6	3.8	3.8 (6)	Nearly uniform color,
6	7.5	.05	STP	4.6	4.0	4.0 (6)	dispersants added to dry bentonite
7	7.5	.05	TSP	4.6	4.0	3.8 (6)	Nearly uniform color,
8	7.5	.05	STP	4.6	4.0	4.1 (6)	dispersants added to water before bentonite
9	10.0	.06	STP	7.5	6.0	5.8 (11)	Mixing conditions simulated --
10	7.5	.045	STP	5.0	4.0	3.2 (11)	10 per cent slurry diluted
11	5.0	.03	STP	3.0	1/2 clear	2/3 clear	
12	10.0	.12	STP	7.8	6.0	5.6 (11)	Mixing conditions simulated --
13	7.5	.09	STP	5.8	4.4	4.0 (11)	10 per cent slurry diluted
14	5.0	.06	STP	3.2	2.8	1/2 clear	

1. Testing by Mr. G. E. Johnson, Chief Engineer, C.N.P.P. and I.D.
2. Each in 1000 cc of canal site water.
3. All tests with Benton Clay Company high-swell type bentonite.
4. Dispersants used -- tetrasodium pyrophosphate (TSP), sodium tripolyphosphate (STP), sodium hexametaphosphate (SHP).
5. Number in parenthesis refers to number of days test was run.
6. Refers to amount of segregation in bentonite-water mixture at end of test.

Enclosure 12

TEST FOR EFFECT OF TEMPERATURE ON HYDROMETER READING OF BENTONITE SOLUTION

SOLUTION MIXTURE CONTAINED
1000 cc WATER - 10 GRAMS BENTONITE - 0.06 GRAM TRI POLY PHOSPHATE



NOTES ON TESTS

(1) Test started with temperature of solution at 58° F. Solution warmed at room temperature and remixed in test cylinder each time before readings were taken.

(2) Placed 80° F solution in refrigerator. Readings were taken at 60 58 55 50 45 42 38 and 35° F. Solution remixed each time before readings were taken.

(3) Solution remained in refrigerator for 12 hours, then removed to warm room. Solution allowed to stand without movement. Hydrometer and thermometer left in solution.

Tests started 4-15-54, completed 4-19-54.

THE CENTRAL NEBRASKA PUBLIC POWER & IRRIGATION DISTRICT. HASTINGS, NEBR.

Geo E Johnson
CHIEF ENGINEER

Enclosure 13

Hydrometer Readings
Tri-County Project Installation

Section	Station	4-5-54	4-6-54	4-7-54	4-8-54	4-9-54	4-10-54	4-11-54	4-12-54	4-14-54	4-15-54
		Hydrometer Readings[1] -- Time of Reading -- Temperature									
1	23.8	7.4 4:10p Sample 1 clear Sample 2 Mi 24.0 6.9 7:20a	6.0 7:45a 5.9 11:00a 7.2 2:40p	7.2 10:00a 6.8 2:30p 7.0 7:40p	9.2 9:55a Sample 7 2:30p 2.0 4:00p clear Mi 24.0 7.3 4:15p			Above headgate 2.2 54°F clear			
Ck 24.6 2	24.6	Sample 3 7.4 7:30p	5.0 9:15a 8.0[3] 9:15a 6.0 11:10a 7.0[3] 11:10a	Sample 6 6.4 9:45a 5.9 2:20p 5.4 7:35p	7.2 9:35a 7.2 4:20p						
	25.0		6.2 11:15a 6.4 2:10p 6.0 5:20p	6.3 9:10a 6.2 2:10p 5.4 7:10p	7.0 9:25a 7.6 4:30p	2.2 11:05a 2.0 2:00p clear					
	26.0		6.0 11:20a 6.0 2:20p	Sample 5 6.2 9:00a 6.0 2:00p 6.2 7:00p	6.4 9:15a 6.2 4:48p	3.0 10:50a 2.0 1:50p					
Ck 26.0 3	26.3				6.2 9:10a	8.4 10:40a 4.4 1:30p 6.6[3] 1:30p	clear				
	27.4		6.0 11:30a		5.0 9:00a	6.4 9:15a 7.4 2:36p	2.4 52°F				
	27.9		6.0 11:40a 5.0 5:42p	Sample 4 6.0 8:30a 6.0 1:45p 5.4 6:30p	6.3 8:50a 6.2 4:52p	6.6 9:10a 4.4 3:01p 6.9[3] 3:01p	3.0 52°F 3.0 52°F 3.4 51°F below ck				
Ck 27.9 4	28.2				6.2 8:45a						
	28.7				6.2 8:30a 6.2 5:00p	6.2 9:01a 5.5 3:20p 59°F 6.1[3] 3:20p 54°F	5.6 50°F				
Ck 28.7 5	30.2					6.4 8:55a	6.6 48°F 6.8[3] 48°F	2.2 55°F 2.4 53°F clear			
	30.6					6.4 8:50a 4.8 3:40p 66°F	6.2 52°F	2.2 54°F clear			
	31.3					8.0 8:45a 5.6 4:00p 78°F	6.0 56°F 12.0[3] 51°F	2.4 54°F 6.6[3] 52°F			
Ck 31.3 6	32.0							4.1 56°F 5.0[3] 52°F	2.2 56°F clear		
	32.8								6.2 54°F ditch ¼ full		
Ck 32.8 7	33.3								6.5 58°F		
	35.0									1.8 62°F 2.0 60°F clear	
	35.5									3.0 66°F 5.4[3] 58°F	2.6 51°F clear
Ck 35.5 8 Ck 36.2	36.2										3.0 50°F

[1] With extra sensitive soil hydrometer(range 0-10 grams/liter)--not corrected for temperature.

[2] Reading of clear ditch water -- 2.2; reading of mixture just below dilution point -- 9.0.

[3] Sample collected off bottom of pond; all other samples were collected off surface.

Note: Samples were analyzed in USBR Denver Laboratories.
No readings for 4-13-54 and 4-16-54.

Flocculation Tendency upon Dilution

Bentonitic water collected in canal at Mile 23.8 just below mix point (hydrometer reading 9.0) -- clear water collected from main lateral just above mix point.

Sample No.	Ml of Clear Water	Ml of Bent. Water	Appearance after Setting 24 hrs
1	400	100	Flocculation -- clear water above
2	300	200	Flocculation -- clear water above
3	200	300	Separation -- but cloudy water above
4	150	350	Separation -- but cloudy water above
5	100	400	Separation -- but cloudy water above
6	0	500	Some layering but no clear water above

Enclosure 14

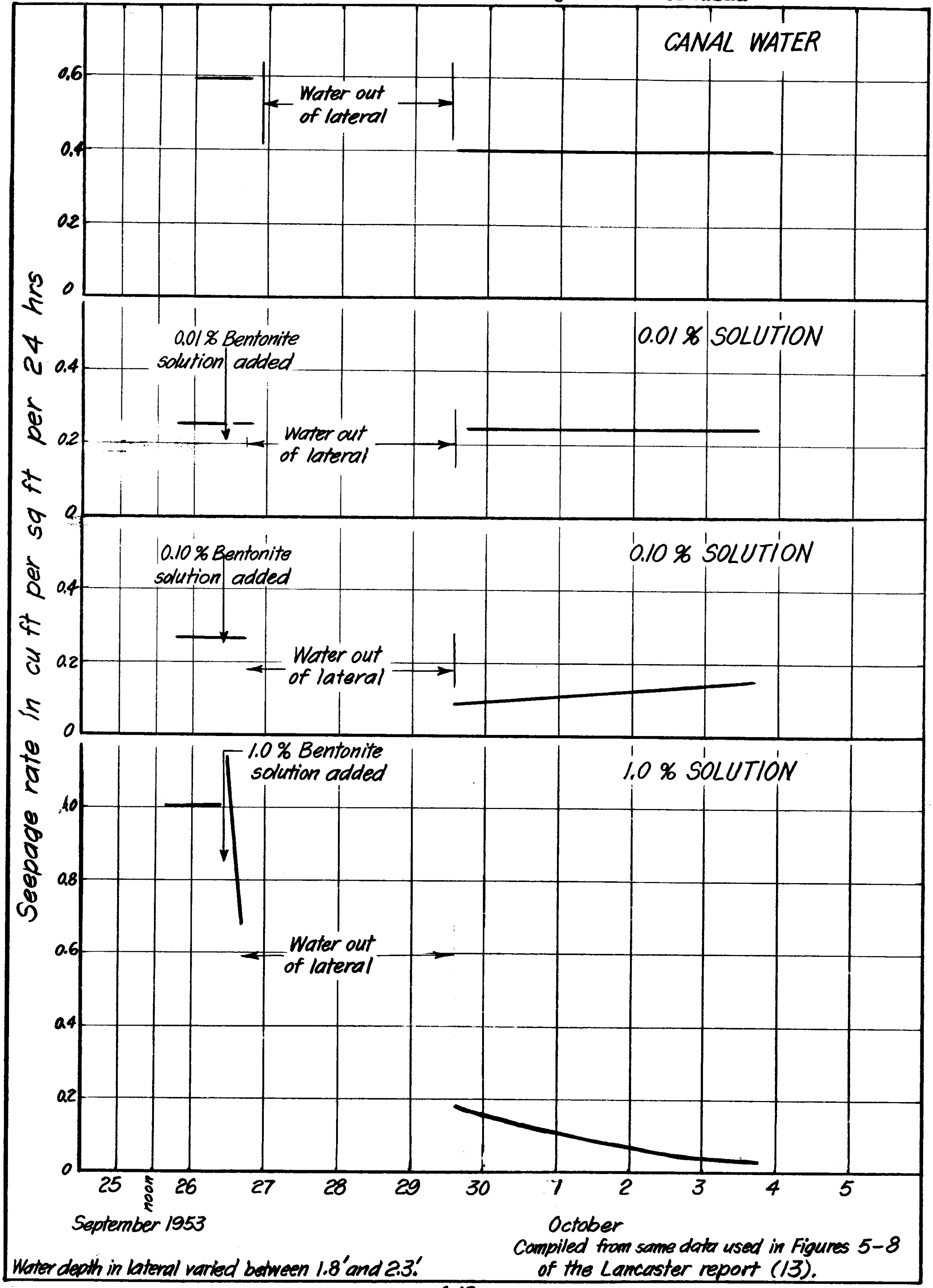
Chemical Analyses of Sedimenting Water Samples[1]

Tri-County Project Installation

Field No.	Lab No.	Location	Date and Time	Hyd Rd	pH	TDS	TSS	Chemical Analysis parts per million over milliequivalents per liter: Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	% Na	Hard. $CaCO_3$
1	A3581	Headgate Mi 23.7 Clear Mix Water	4-5-54 8:00 p.m.	2.2	7.8	568	--	61 3.07	22 1.80	72 3.15	11 0.28	0 0	174 2.86	231 4.82	27 0.76	38.0	233
2	A3582	Bridge Mi 24.0 Mixture	4-5-54 7:20 p.m.	6.9	8.3	700	4552	22 1.12	8.6 0.72	179 7.8	8.6 0.22	0 0	208 3.41	264 5.5	32 0.91	79.1	92
3	A3583	Above check-Drop Mi 24.6 -- Mix	4-5-54 7:30 p.m.	7.4	8.3	690	5594	28 1.39	11 0.91	167 7.26	9.4 0.24	0 0	204 3.35	266 5.54	38 1.08	74.1	115
4	A3584	Above check-Drop Mi 27.9 -- Mix	4-7-54 8:30 a.m.	6.0	8.2	708	3427	28 1.41	14 1.20	167 7.26	10. 0.26	0 0	210 3.44	276 5.75	33 0.92	71.7	80.5
5	A3585	Above check - Culvert Mi 26.0 -- Mix	4-7-54 9:00 a.m.	6.2	8.3	696	3866	26 1.31	12 0.96	168 7.32	9.4 0.24	0 0	209 3.42	266 5.55	29 0.83	74.5	113
6	A3586	Above check-Drop Mi 24.6 -- Mix	4-7-54 9:45 a.m.	6.4	8.4	698	3923	21 1.06	9.5 0.79	184 8.00	9.8 0.25	3.3 0.11	204 3.35	263 5.47	34 0.96	79.2	92.5
7	A3587	Bridge Mile 24.0 Mix	4-8-54 2:30 p.m.	9.0	8.4	734	6289	15 0.77	4.2 0.35	213 9.24	6.2 0.16	3.0 0.10	207 3.39	297 6.18	34 0.96	87.8	56.0
1	A3454	Sub-Lat 19.3 Head Clear Mix Water	2-9-54 8:00 p.m.	2.2		654	312	70 3.52	26 2.13	3.45							282
2	A3456	Sub-Lat 19.3 Head Mix	2-9-54 8:00 p.m.	7.0		672	5977	31 1.57	16 1.27	6.50							142
3	A3457	Sub-Lat 19.3 Mix	2-10-54 9:00 a.m.	-		692	1447	41 2.06	17 1.36	6.08							171
4	A3555	Sub-Lat 19.3 Clear Mix Water	2-10-54 9:30 a.m.	-		690	347	40 1.99	16 1.31	5.82							165

[1] By Bureau of Reclamation -- Engineering Labs -- Chemical Lab -- Denver, Colorado

Enclosure 15 Results of Feasibility Tests in Dune Sand Materials
Horse Creek Lateral -- North Platte Project -- Nebraska



Enclosure 16

Volume of Ponds
North Platte Project Installation
Horse Creek Lateral -- Mile 9.3 to 20.9

Section	Ponding Structures	Approx Volume[1] cu ft	Approx Wet Area[2] sq yd
1	Mile 9.3 to Mile 11.0	323,000	22,000
2	" 11.0 " " 11.9	171,100	9,500
3	" 11.9 " " 13.3	207,000	13,600
4	" 13.3 " " 13.7	59,100	4,220
5	" 13.7 " " 15.2	221,800	15,840
6	" 15.2 " " 16.2	153,000	10,000
7	" 16.2 " " 17.4	145,700	12,200
8	" 17.4 " " 18.2	88,700	8,000
9	" 18.2 " " 19.5	123,600	11,500
10	" 19.5 " " 20.0	43,600	4,110
11	" 20.0 " " 20.9	82,000	7,660

[1] Very rough approximation owing to irregular section of this old lateral.

[2] Wetted canal perimeter area.

Note: Inflow of drain water possible because of this initial concentration -- 2 per cent. It was assumed that 320,000 cubic feet of mixture would be ample, especially since the volume could be greatly increased by inflow dilution. Calculation as follows:

$$\frac{320{,}000 \times 52.4 \times .02}{2000} = \underline{200} \text{ tons bentonite}$$

Available funds sufficient for 175 tons bentonite.

Enclosure 17

Hydrometer Readings
Horse Creek Lateral Sediment Lining Installation
North Platte Project -- Wyoming

Station	4-25-54	4-26-54	4-27-54	4-28-54	4-29-54	5- 1-54	5- 2-54	5- 3-54	5- 4-54	5- 5-54	5- 6-54	5- 7-54	5-10-54
7.6	24.0 18.5°	30.0 18°											
9.3	7.0 15° 15.0 21°	9.0[3] 17° 9.0[2] 18°											
11.0	7.0[3] 13° 3.0[2] 21°	12.0[3] 16° 7.0[2] 15°	7.0[3] 16° 8.0[2] 16°		1.0[4] 9°								
11.9			9.0[3] 16° 6.0[2] 21°	6.0 17°	5.0 9°								
13.3			13.0[3] 14° 8.9[2] 21°		9.0 9°	3.0[3] 5°							
13.7				8.0 17°	9.0 5°	4.0[3] 4°		1.0[4] 11°					
15.2				12.0 15° 9.0 20°	11.0 4°	9.0[3] 4°	7.0[2] 3°	2.0 10°					
16.2				4.0 13° 2.5 21°	9.0 15°	10.0[2] 3°		4.0 12°	2.0 11°				
17.4				2.0 22°			8.0[3] 8°	7.0 14°	4.0 11°	2.0 12°	2.0 13°		
18.2					4.0 8°			8.0 12°	6.0 11°	4.0 12°	3.0 13°		
19.5								5.0 22°	8.0 10°	5.5 12°	3.0 13°	2.0 16°	3.0 10°
20.0										8.5 10°	5.0 13°	4.5 17°	5.0 11°
20.9											7.0[2] 12°		6.0 10°

[1] With sensitive soil hydrometer -- range 0-10 grams/liter.

[2] Above structure.

[3] Below structure.

[4] Clear water.

Note: All temperatures recorded in Centigrade.
No readings included for mixtures on 4-24-54 owing to mixing problems(producing wide variation in concentration and suitability of mix.

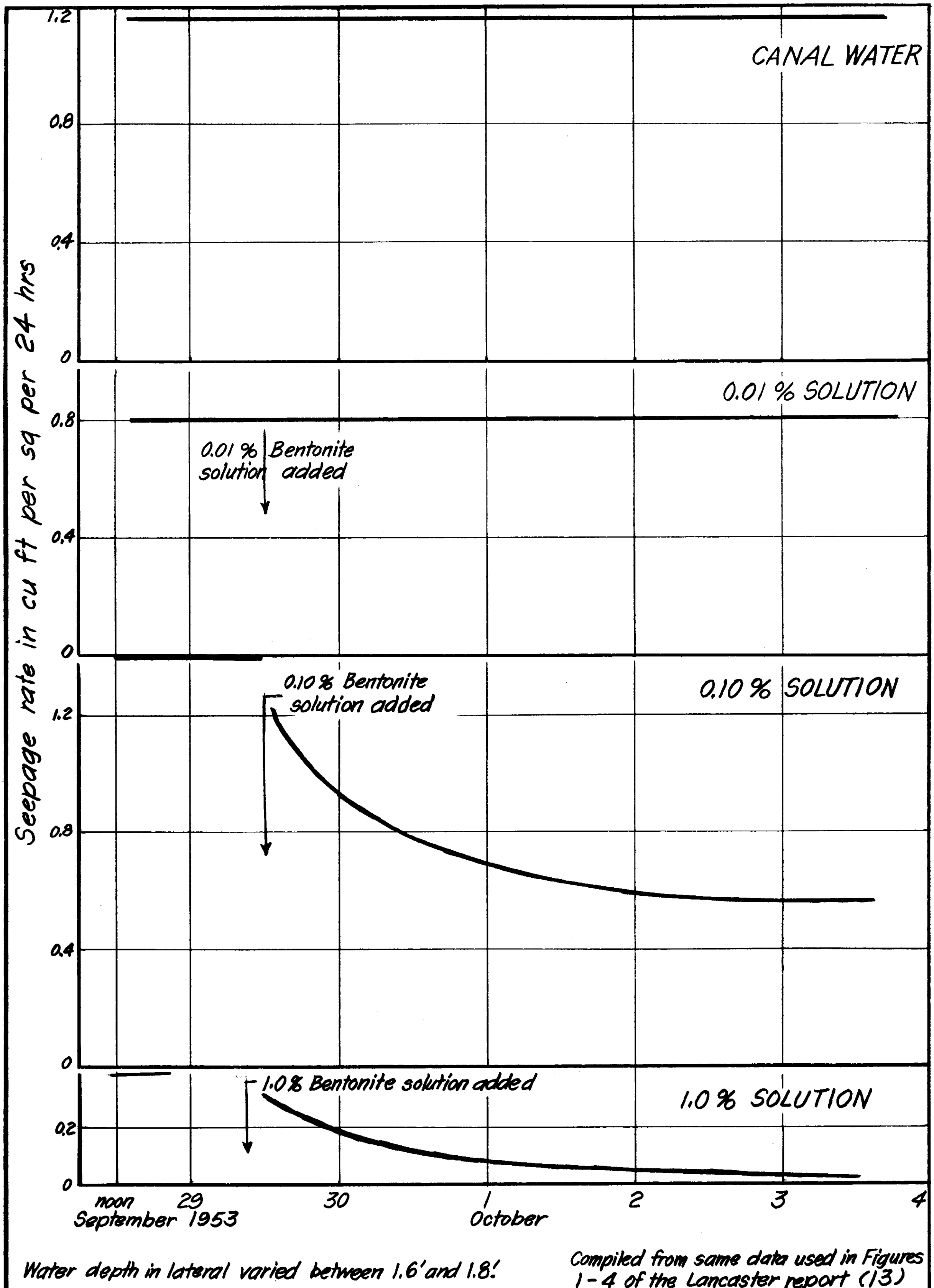
Enclosure 18

Chemical Analyses of Sedimenting Water Samples[1]
North Platte Project Installation

Field No.	Lab No.	Location	Date	Hyd Rd	pH	TDS	TSS	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	% Na	Hard. $CaCO_3$
								Chemical Analysis parts per million over milliequivalents per liter									
1	A3589	Clear Water Pond Mi 7.5	4-25-54	3.0	8.6	1048	26	18 0.92	5.4 0.45	384 16.68	10 0.26	18 0.60	564 9.24	345 7.18	45 1.26	91.1	68.5
2	A3590	Mixture at Mile 7.7	4-25-54	9.0	8.3	1148	13,300	22 1.08	6.6 0.55	500 21.75	7.8 0.20	3.6 0.12	666 10.9	426 8.87	129 3.64	92.2	81.5
3	A3591	Clear Water Pond Mi 7.5	4-26-54	2.5	8.8	1056	36	15 0.76	2.4 0.20	370 16.10	7.8 0.20	37 1.24	515 8.45	328 6.84	36 1.02	93.3	48.0
4	A3592	Mix at Mile 7.7	4-26-54	25.0	8.7	2180	20,500	25 1.27	7.0 0.58	637 27.7	7.8 0.20	30 1.00	659 10.8	808 16.83	48 1.36	93.1	92.5
5	A3593	Mix below check at Mi 11.9	4-27-54	9.0	8.2	1032	7,304	19 0.96	5.2 0.43	393 17.10	5.9 0.15	-- --	570 9.34	354 7.37	33 0.92	91.7	69.5
6	A3594	Mix below check at Mi 11.0	4-27-54	8.0	8.0	1024	5,840	14 0.72	6.6 0.55	370 16.10	7.8 0.20	--- --	530 8.69	347 7.23	35 0.98	91.6	63.5
7	A3595	Mix at bridge near Mi 10.2	4-27-54	2.0	8.5	988	1,180	13 0.65	4.7 0.39	345 15.00	7.8 0.20	10 0.34	526 8.62	288 6.01	35 0.98	98.4	52.0
8	A3596	Clear Water at Mi 7.5	4-27-54	0.0	9.0	1012	38	14 0.68	4.3 0.36	345 15.00	7.8 0.20	47 1.58	477 7.82	306 6.37	33 0.92	92.4	52.0
9	A3597	Mix at check Mi 13.3	4-28-54	8.5	8.4	1100	4,628	17 0.84	5.2 0.43	403 17.50	7.8 0.20	7.8 0.26	567 9.30	371 7.73	40 1.12	92.3	63.5
10	A3598	Mix at bridge near Mi 16.6	4-28-54	4.0	8.5	1072	3,596	15 0.76	2.9 0.24	362 15.75	11 0.28	12 0.40	543 8.90	285 5.93	42 1.18	92.5	50.0

[1] By Bureau of Reclamation -- Engineering Labs -- Chemical Lab -- Denver, Colorado

Enclosure 19 Results of Feasibility Tests in Fractured Shale Materials
Lateral 128 -- Kendrick Project -- Wyoming



Enclosure 20

Hydrometer Readings
Lateral 128 Sediment Lining Installation
Kendrick Project -- Wyoming

Station	Hydrometer[1] Readings -- Temperature				
	5-13-54	5-14-54	5-15-54	5-16-54	5-17-54
0	13.0 17°[4]				
Mi 0.6	13.0 17° 7.0[2] 15°	3.0[2] 15°			
Mi 1.4		7.0 16°			
Mi 1.8			3.5[3] 13° -1.0[2,4] 18°		
Mi 2.1			4.0 14°		-0.5 18°
Mi 2.8			3. 5 13°		
Mi 3.3			3.0 18°	3.0 16°	
Mi 3.8					-1.0 19°
Mi 5.0					-1.5 23.5°

[1] With sensitive soil hydrometer -- range 0-10 gms/liter.

[2] Above structure.

[3] Below structure.

[4] Clear water.

Enclosure 21

Chemical Analyses of Sedimenting Water Samples [1]
Kendrick Project Installation

Field No.	Lab No.	Location	Date	Hyd Rd	pH	TDS	TSS	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	% Na	Hard. $CaCO_3$
								Chemical Analysis parts per million over milliequivalents per liter									
1	A3661	Clear Water Mi 0	5-13-54	0	7.8	376	100	51 2.56	18 1.46	38 1.67	3.5 0.09	- -	140 2.30	148 3.08	9.2 0.26	28.9	201
2	A3660	Mix at Mi 0.1	5-13-54	7.0	8.0	568	8652	12 0.60	9.2 0.75	170 7.40	5.9 0.15	- -	190 3.11	208 4.34	14 0.40	83.1	67.5
3	A3663	Mix at Mi 0.2	5-31-54	4.5	7.8	472	4136	15 0.76	7.7 0.63	119 5.16	4.7 0.12	- -	159 2.60	180 3.74	11 0.31	77.4	69.5
4	A3664	Mix at Mi 0.4	5-13-54	9.0	7.8	522	8362	11 0.56	6.8 0.56	145 6.32	2.0 0.05	- -	155 2.54	187 3.89	10 0.29	84.4	56.0
5	A3662	Mix at Mi 0.6	5-13-54	6.0	7.8	708	18100	16 0.78	8.4 0.69	199 8.66	3.5 0.09	- -	219 3.59	258 5.37	18 0.51	84.7	73.5
6	A3665	Mix at Mi 0.6	5-14-54	3.0	8.2	456	2504	25 1.24	12 0.99	109 4.68	3.5 0.09	- -	171 2.80	172 3.59	10 0.29	66.9	111
7	A3666	Mix at Mi 1.6	5-14-54	7.0	7.8	916	5792	49 2.43	21 1.71	204 8.86	5.9 0.15	- -	166 2.72	462 9.62	16 0.44	67.4	207
8	A3667	Mix at Mi 3.3	5-15-54	3.0	8.0	776	2988	46 2.31	7.9 0.65	161 7.02	5.1 0.13	- -	183 3.00	365 7.60	17 0.48	69.4	148
9	A3668	Mix at Mi 5.0	5-17-54	-1.5	7.8	470	630	35 1.73	14 1.14	92 4.00	4.7 0.12	- -	171 2.80	176 3.67	12 0.33	57.2	143

[1] By Bureau of Reclamation -- Engineering Labs -- Chemical Lab -- Denver, Colorado