INTERIM REPORT

ON

BENTONITE SEDIMENT SEALING ACTIVITIES

IN

LATERAL E-65-19.3

of

THE CENTRAL NEBRAKSA PUBLIC POWER AND IRRIGATION DISTRICT

NEAR

BERTRAND, NEBRASKA

By

R. D. Dirmeyer Jr.
Project Leader

prepared for
Agricultural Research Service
U. S. Department of Agriculture--

under terms of
ARS Contract No. 12-14-100-507(41)
CSU Research Foundation Project 108

Colorado State University Experiment Station
Civil Engineering Section
Fort Collins, Colorado

Preliminary Report--Subject to Revision

June 1958 CER58RDD23

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PREFACE

Research investigations -- relating to the development of low-cost methods of sealing irrigation canals with water-borne bentonite or colloidal clay -- have been carried on at Colorado State University in Fort Collins since July 1953. The work has been accomplished through the Experiment Station and the Research Foundation.

Because of the practical objectives of the research project investigations, the field trial type of development work has been emphasized. This emphasis is also related to the major source of the project research funds. During the early work from July 1953 to January 1957, almost all of the research studies were financed by canal construction or operating groups, such as the Bureau of Reclamation and private irrigation companies and districts. Important help was also received from companies with a direct commercial interest, such as bentonite, chemical and mixing equipment companies.

Starting in July 1956, CSU Experiment Station funds were allotted to the research and development project. However, even with this important help, it was still necessary to continue to receive a major portion of the project funds from other co-operators in the program.

In January 1957, a contract -- relating to the sediment sealing investigations -- was entered into between the U. S. Department of Agriculture and the University. Important provisions of this contract are outlined below:

1. It provides a major amount of supplemental research funds for the canal sealing investigations at the University.

2. Administration of the contract funds is carried out by the Agricultural Research Service through its Western Soil and Water Management Research Branch.

3. It is effective for the period of January 14, 1957 to January 14, 1960.

4. It provides for detailed investigations at not less than three and not more than six field installations.

In selecting the field installation sites for the detailed research and development studies, priority was given to those sites where the local irrigation company or district was:

1. Already an active co-operator in the University's sediment sealing research program;

2. Willing to pay all of the installation costs of a new trial in their canal system and help out on the University evaluation costs not fully covered in the project budget of ARS contract and Experiment Station funds.

In addition to the above factors, it was also necessary to choose sites that were representative -- from both the standpoints of:

1. The past sedimenting installations previously made in the States of Colorado, Nebraska, Wyoming, South Dakota, Arizona, and California;

2. The kinds of pervious bed materials and operating conditions commonly encountered in irrigation canals in the western United States.

To date, five representative sites have been selected for the contract program. They are listed in the tabulation on the following page. The site locations are shown on a map (Fig. 1) on the next page after the tabulation.

This report is the second of five separate interim reports that are to be completed -- one for each site -- by July 1958. The reports are being prepared at the request of Mr. Lloyd E. Myers Jr., who is the officially designated contract representative for the Agricultural Research Service of the U. S. Department of Agriculture.

Each of the reports is of a preliminary nature, designed to provide the following:

1. An up-to-date tabulation of research and development data, including the limited evaluation results that are available at the present time;

2. Tentative plans for the future research and development activities at each field installation site.

It will be realized that this is not a final report -- nor is it in the anticipated form or organization of the final reports which are scheduled for completion by January 1960.

LIST OF RESEARCH SITES

Pervious Material	Canal Site
Fractured rock to coarse rock talus	Connection Canal -- 7700' section Trans-Mountain Diversion System near Aspen, Colorado The Twin Lakes Reservoir and Canal Company, Ordway, Colorado
Sandy to gravelly alluvial material	West side supply ditch -- 1 mi. sec. Experimental Farm near Center, Colorado Adolph Coors Company, Golden, Colo.
Dune sand with alluvial clay to sand	Coachella Canal -- Reach No. 2 -- 8 mile section -- near Holtville, California Imperial Irrigation District, Imperial, California
Dune sand	Lateral 1 -- 1st 6 miles -- near Torrington, Wyoming North Platte Project (USBR) Pathfinder Irrigation District, Mitchell, Nebraska
Loessial soil -- wind-deposited clayey silt	Lateral 19.3 -- 1st 4.4 miles -- near Bertrand, Nebraska E-65 Main Lateral System The Central Nebraska Public Power and Irrigation District, Holdrege, Nebraska

The major co-operator at each site is underlined.

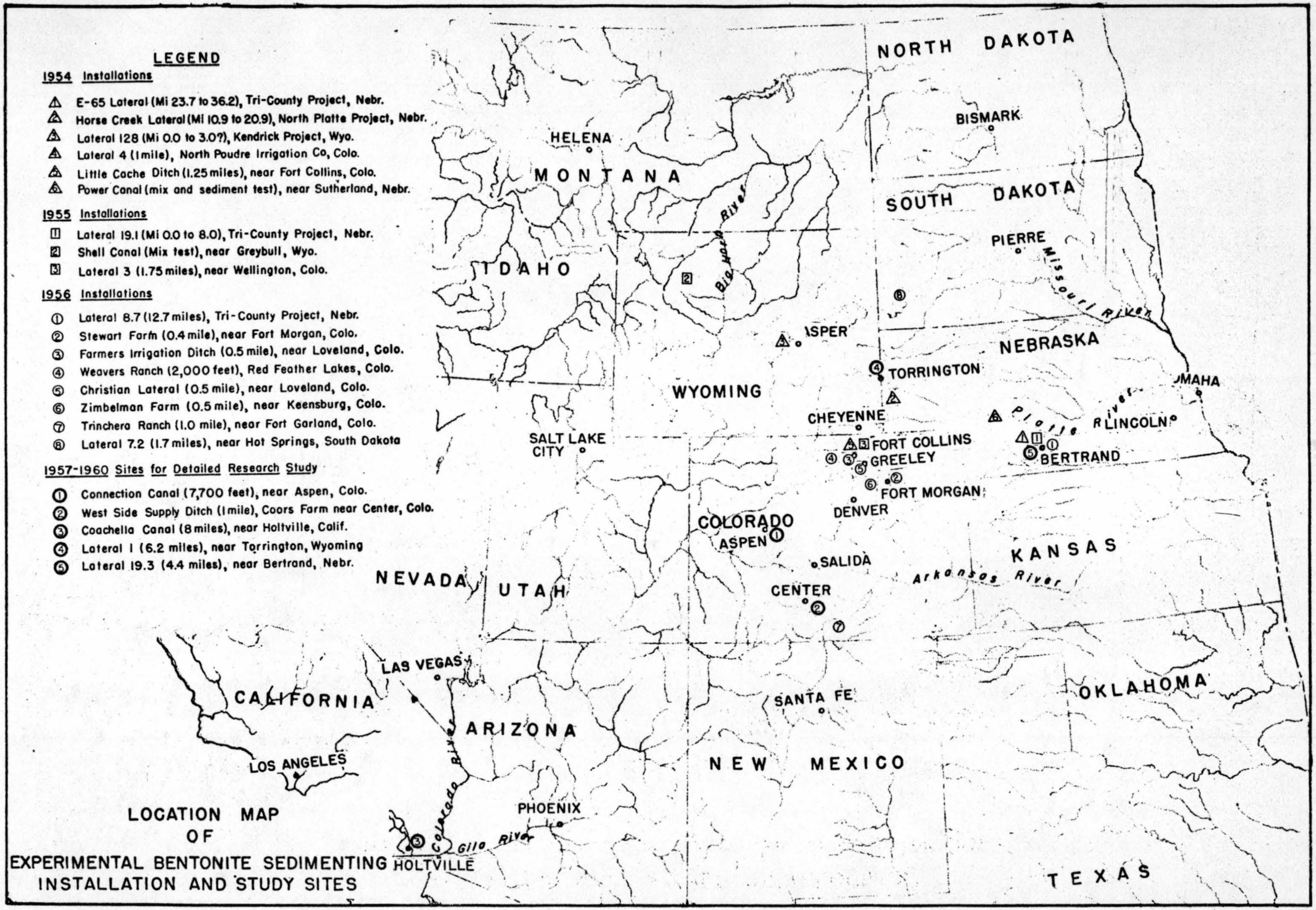
LEGEND
1954 Installations
E-65 Lateral (Mi 23.7 to 36.2), Tri-County Project, Nebr.
Horse Creek Lateral (Mi 10.9 to 20.9), North Platte Project, Nebr.
Lateral 128 (Mi 0.0 to 3.07), Kendrick Project, Wyo.
Lateral 4 (1 mile), North Poudre Irrigation Co, Colo.
Little Cache Ditch (1.25 miles), near Fort Collins, Colo.
Power Canal (mix and sediment test), near Sutherland, Nebr.
1955 Installations
Lateral 19.1 (Mi 0.0 to 8.0), Tri-County Project, Nebr.
Shell Canal (Mix test), near Greybull, Wyo.
Lateral 3 (1.75 miles), near Wellington, Colo.
1956 Installations
Lateral 8.7 (12.7 miles), Tri-County Project, Nebr.
Stewart Farm (0.4 mile), near Fort Morgan, Colo.
Farmers Irrigation Ditch (0.5 mile), near Loveland, Colo.
Weavers Ranch (2,000 feet), Red Feather Lakes, Colo.
Christian Lateral (0.5 mile), near Loveland, Colo.
Zimbelman Farm (0.5 mile), near Keensburg, Colo.
Trinchera Ranch (1.0 mile), near Fort Garland, Colo.
Lateral 7.2 (1.7 miles), near Hot Springs, South Dakota
1957-1960 Sites for Detailed Research Study
Connection Canal (7,700 feet), near Aspen, Colo.
West Side Supply Ditch (1 mile), Coors Farm near Center, Colo.
Coachella Canal (8 miles), near Holtville, Calif.
Lateral 1 (6.2 miles), near Torrington, Wyoming
Lateral 19.3 (4.4 miles), near Bertrand, Nebr.
NORTH DAKOTA
BISMARK
HELENA
MONTANA
SOUTH DAKOTA
PIERRE
Missouri River
Big Horn River
IDAHO
ASPER
NEBRASKA
TORRINGTON
OMAHA
WYOMING
CHEYENNE
Platte River
LINCOLN
SALT LAKE CITY
FORT COLLINS
GREELEY
BERTRAND
FORT MORGAN
DENVER
COLORADO
ASPEN
KANSAS
SALIDA
Arkansas River
NEVADA
UTAH
CENTER
LAS VEGAS
OKLAHOMA
CALIFORNIA
SANTA FE
ARIZONA
LOS ANGELES
NEW MEXICO
Colorado River
PHOENIX
Gila River
HOLTVILLE
TEXAS
LOCATION MAP OF EXPERIMENTAL BENTONITE SEDIMENTING INSTALLATION AND STUDY SITES

Figure 1

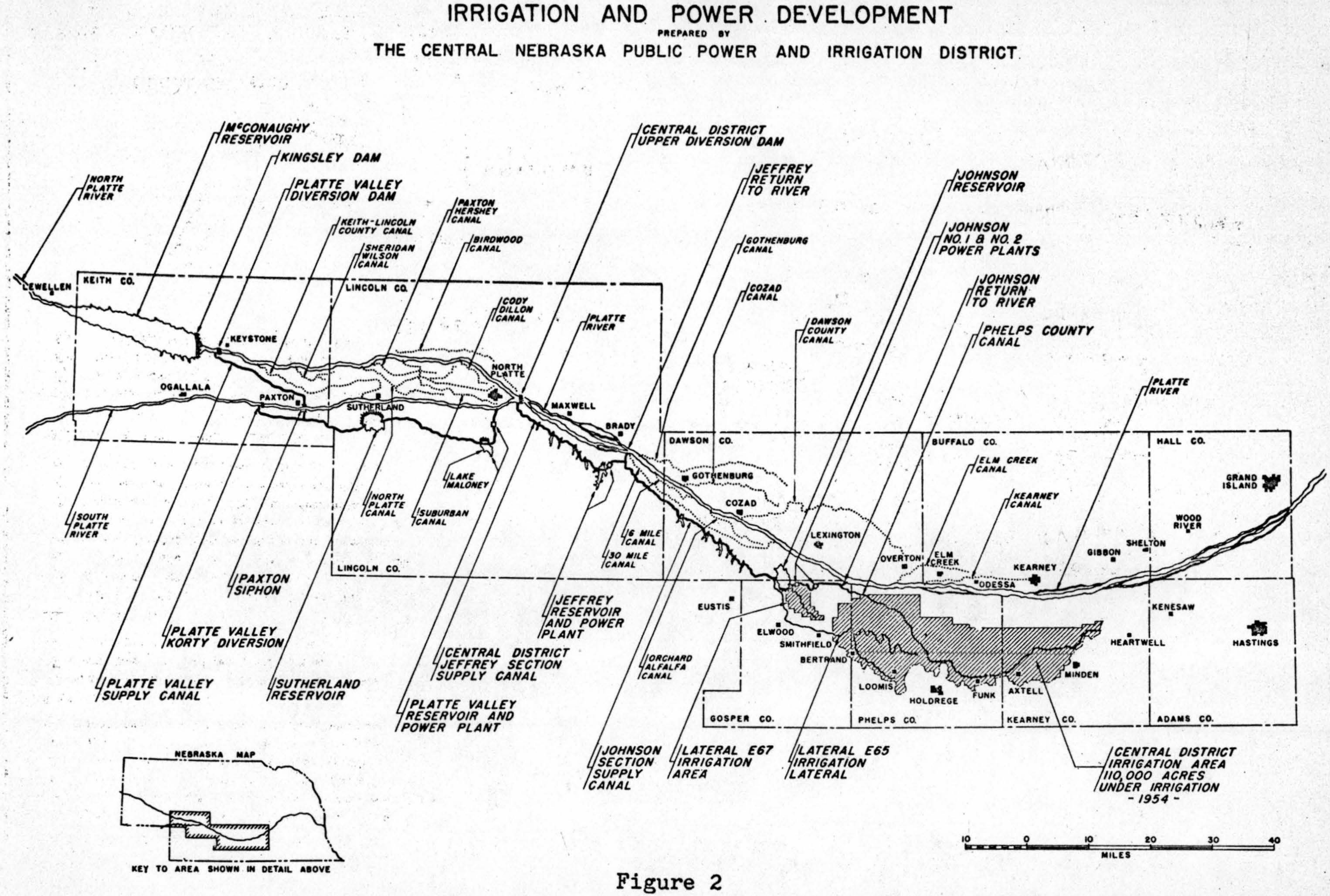
IRRIGATION AND POWER DEVELOPMENT
PREPARED BY
THE CENTRAL NEBRASKA PUBLIC POWER AND IRRIGATION DISTRICT
McCONAUGHY RESERVOIR
KINGSLEY DAM
PLATTE VALLEY DIVERSION DAM
NORTH PLATTE RIVER
KEITH-LINCOLN COUNTY CANAL
SHERIDAN WILSON CANAL
PAXTON HERSHEY CANAL
BIRDWOOD CANAL
CODY DILLON CANAL
CENTRAL DISTRICT UPPER DIVERSION DAM
PLATTE RIVER
JEFFREY RETURN TO RIVER
GOTHENBURG CANAL
COZAD CANAL
DAWSON COUNTY CANAL
JOHNSON RESERVOIR
JOHNSON NO. 1 & NO. 2 POWER PLANTS
JOHNSON RETURN TO RIVER
PHELPS COUNTY CANAL
PLATTE RIVER
LEWELLEN
KEITH CO.
LINCOLN CO.
KEYSTONE
OGALLALA
PAXTON
SUTHERLAND
NORTH PLATTE
MAXWELL
BRADY
DAWSON CO.
GOTHENBURG
COZAD
LEXINGTON
OVERTON
ELM CREEK
ODESSA
KEARNEY
BUFFALO CO.
HALL CO.
GRAND ISLAND
WOOD RIVER
GIBBON
SHELTON
ELM CREEK CANAL
KEARNEY CANAL
LAKE MALONEY
NORTH PLATTE CANAL
SUBURBAN CANAL
SOUTH PLATTE RIVER
6 MILE CANAL
30 MILE CANAL
LINCOLN CO.
PAXTON SIPHON
PLATTE VALLEY KORTY DIVERSION
PLATTE VALLEY SUPPLY CANAL
SUTHERLAND RESERVOIR
JEFFREY RESERVOIR AND POWER PLANT
CENTRAL DISTRICT JEFFREY SECTION SUPPLY CANAL
PLATTE VALLEY RESERVOIR AND POWER PLANT
ORCHARD ALFALFA CANAL
EUSTIS
ELWOOD
SMITHFIELD
BERTRAND
LOOMIS
HOLDREGE
FUNK
AXTELL
MINDEN
KENESAW
HEARTWELL
HASTINGS
GOSPER CO.
PHELPS CO.
KEARNEY CO.
ADAMS CO.
JOHNSON SECTION SUPPLY CANAL
LATERAL E67 IRRIGATION AREA
LATERAL E65 IRRIGATION LATERAL
CENTRAL DISTRICT IRRIGATION AREA 110,000 ACRES UNDER IRRIGATION - 1954 -
NEBRASKA MAP
KEY TO AREA SHOWN IN DETAIL ABOVE
10 0 10 20 30 40
MILES

Figure 2

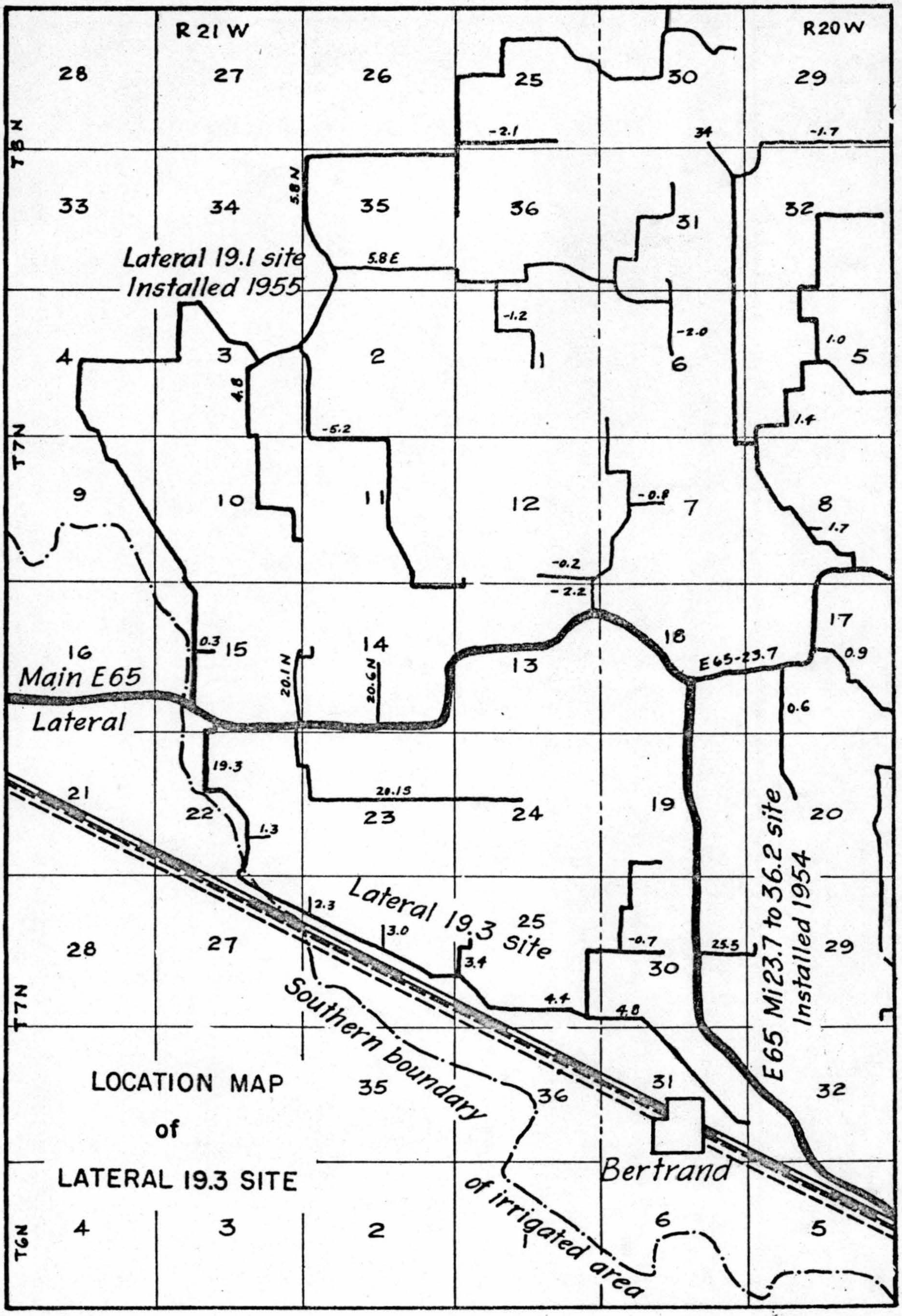
R 21 W
R20 W
T8N
T7N
T7N
T6N
Lateral 19.1 site
Installed 1955
Main E65
Lateral
E65-23.7
Lateral 19.3 Site
E65 Mi 23.7 to 36.2 site
Installed 1954
Southern boundary
of irrigated area
Bertrand
LOCATION MAP
of
LATERAL 19.3 SITE

Figure 3

CONTENTS

INTRODUCTION

The Central Nebraska Public Power and Irrigation District has been co-operating with the Sediment Sealing Research Project at Colorado State University since September 1953. The actual sedimenting work -- including procedure development work and several trial installations -- has been carried on in the E-65 Main Lateral System of the District (see Figs. 2 and 3).

The E-65 Main Lateral is so named because it takes off from the Main Supply Canal at Mile 65, just above the inlet to Johnson Lake. It is 54.7 miles long, including its main branch, E65-23.7. The system also includes about 194 miles of distribution laterals, supplying irrigation water to about 34,000 acres of land in the vicinity of Loomis and Bertrand, Nebraska.

The E-65 irrigated area is on the Platte River side of the bench area separating the main valleys of the Platte River and the Republican River. This entire irrigated area is underlain by a thick section of loessial soil. This is a sandy to clayey silt soil with a number of unique features. Because of its unusual characteristics, the loessial soil will be discussed in a separate section later in this report.

The delivery losses in the E-65 system range from as much as 80 percent at the beginning of the irrigation season to a minimum of about 40 percent during the remainder of the season. Since the demand for irrigation water in the E-65 area is greater than the water carrying capacity of the lateral system, this loss is a critical problem -- especially on the lower end of the distribution system. Several methods of easing this problem have been considered by the District engineers. Subsequent development work in this regard has included the following:

1. Supplying supplemental water into the tail-end laterals of the system by pumping -- from both ground water wells and the Phelps County Canal.

2. Investigations into methods of decreasing the high seepage losses of the system -- including installation of several bentonite sedimenting trials.

This report is concerned only with the latter item -- the bentonite sediment sealing activities -- mentioned above.

PEOPLE INVOLVED IN DEVELOPMENT WORK

The District's development work on the bentonite sedimenting method of sealing canals has been accomplished under the general supervision of Mr. George E. Johnson, Chief Engineer, and under the direct supervision of Mr. Ted Johnson, Assistant Chief Engineer. Other district personnel who have actively assisted in the development work include: Mr. L. G. Mathieu, Irrigation Engineer; Mr. Orvin Marquardt, Irrigation Superintendent; Mr. A. W. Hall, Hydraulic Engineer; and Mr. Jack Kepke, Supply Canal Supervisor.

The following personnel of the Sediment Sealing Research Project at the University have assisted in the development activities: the writer, as project leader; Mr. D. L. Bender, as project hydraulic engineer; and Mr. R. T. Shen, as assistant research engineer.

Several members of the Civil Engineering and Agronomy (Soils) Departments of the University have been consulted at various times concerning specific problems at the canal locations or in related laboratory work at the University.

In the early development work, technical assistance and laboratory evaluation help was also received from the Bureau of Reclamation, Chief Engineer and Region 7 offices, in Denver, Colorado.

SUMMARY OF LOESS CHARACTERISTICS

Since the loessial soil has such unusual characteristics, it may be helpful to review briefly some of the more important features of the material before proceeding into the details of the bentonite sediment sealing activities in the District's E-65 area.

The loessial soil in the E-65 area is a sandy to clayey silt material. Its unusual properties are predominantly due to its mode of deposition and formation. It was deposited over a long period of time in a repetitive dust storm type of action. Intervening and subsequent actions, such as those produced by percolating waters and soil-forming processes, have modified the soil to varying extents. In general, however, the soil is commonly characterized by many vertically trending "root and stem holes" or tube-like voids.

As one result of its structure, the soil has differing stability (1) under dry to partially saturated conditions, and (2) after prolonged saturation and loading. Under the dry to partially wet conditions, the soil commonly has a relatively high strength. Upon prolonged saturation and loading, the typical loessial soil will settle. After the settlement is completed, the soil will be denser and more stable than it was before, but during the settlement or transition period, critical and dangerous conditions of foundation settlement and general instability can result.

In the E-65 area, severe and widespread settlement problems are not as yet evident -- but may be possible as a development in the future. To arrive at this conclusion, the following line of reasoning was followed:

1. The loess settlement problems are usually triggered by a significant rise of the ground water level into loessial materials that have not been saturated and settled at some previous time. The actual settlement commonly starts at or just above the rising water table level in the loessial materials.

2. In the E-65 area, the water table is, in general, in excess of 100 feet deep, and for the most part, is confined to an extensive sand and gravel layer that normally is found underlying the thick loessial soil section of this area. It seems unlikely that the water table has recently been significantly higher than it is at the present time.

3. There is no assurance, however, that the water table beneath this irrigated area will remain at its present level. It could make a major rise into the loessial materials at some time in the future.

Thus, canal sealing activities in the E-65 area could have a localized foundation stabilizing effect -- to the extent that the reduction of canal seepage is reflected in a stabilized or reduced water table level beneath the sealed sections of lateral.

The permeability of the loessial soil is also influenced by its structure. In its uncollapsed condition, the soil commonly has a high permeability in a vertical direction and a lower permeability in a horizontal direction. After saturation and collapse of the soil structure, the overall soil permeability is usually reduced and the directional differences lessened or destroyed. However, it is important to realize that other factors can also enter into the permeability considerations. For example, drying cracks that develop between irrigation runs or seasons, or holes produced during the irrigation season by bank weeds or trees or by aquatic animals, such as crayfish, can greatly modify the permeability.

The structure of the soil and especially its permeability and stability characteristics produces a unique response to weathering. The uncollapsed loessial soil commonly weathers to vertical side slopes, such as commonly found in many of the older road and canal cuts in the area. Its weathering under water, however, is strikingly different. The saturated material is erosionally unstable except on very flat slopes and relatively low water velocities.

Several techniques for controlling the settlement and seepage problems in loessial soil under dams and major canal structures have been developed.[1,2] The District has also developed and utilized several methods of controlling the erosion problems -- especially those occurring downstream from major structures on the larger canals. However, none of the methods seem to be directly or economically applicable to the widespread seepage problems of the E-65 system.

At the first glance, the problem of reducing the seepage loss from the E-65 laterals would appear simple to solve. Since the seepage loss occurs mostly through larger holes or voids, such as "root and stem holes", crayfish burrows, and drying cracks, one of the easiest methods of seepage control would consist of breaking up the seepage holes and recompacting the soil back into place. This approach to the problem has considerable merit and, especially in new construction on small laterals in loessial materials, serious consideration should undoubtedly be given to compacting the laterals with heavy V-shaped or U-shaped rollers in place of the normal excavation methods. On the larger laterals, thick compacted earth linings, constructed from the in-place soils, would probably provide adequate service. However, in the E-65 system that is already constructed and operated continuously from early spring to late

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[1] Johnson, G. E., Stabilization of Soil by Silt Injection Method, Proc, Am Soc of Civil Engineers, V 79, Separate No. 323, Nov 53.

[2] Holtz, W. G. and Gibbs, H. J., Consolidation and Related Properties of Loessial Soils, Am Soc for Testing Mat'ls., Special Technical Publication No. 126, 1952, pp 9-33.

fall, the compaction methods do not appear feasible -- at least not for large scale operations. Even if the District could feasibly finance a reasonable amount of the compaction work, it would be exceedingly difficult to accomplish a large program of the work under the winter conditions that commonly prevail in the area.

The investigations of the bentonite sedimenting methods of sealing laterals are being carried on by the District with the hope of developing a satisfactory and economically feasible solution to the seepage problems mentioned above.

SUMMARY AND CONCLUSIONS FROM PAST WORK

During the past four years, the District has installed bentonite sedimenting trials in three sections of lateral in the E-65 area. The trial work has been discussed in considerable detail in past project reports.[3, 4] Some of the more important details of the trials are summarized briefly in TABLE I on the following page.

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[3] Dirmeyer, R. D. Jr., Report of Sediment Lining Investigations, FY 1954 and FY 1955, Colo. A and M College, Rpt. No. 55RDD7, June 55.

[4] Dirmeyer, R. D. Jr., Report of Sediment Lining Investigations, FY 1956, Colo. A and M College, Rpt. No. 56RDD17, August 56.

TABLE I
SUMMARY OF TRIAL DATA

Lateral Section	Design Capacity Length Treated Install. Dates	Bentonite Dispersant Misc. Data	Total Cost Cost/Sq. Yd. Cost/Mile
E-65 Main Lat. Mi 23.7 to 36.2	100 to 68 cfs 12.5 miles 4-5 to 4-16-54	403 tons 6000 lbs. **	$ 15,000 $ .075 $ 1,200
E-65-19.1 T.O.* to 5.8N-2.2	60 cfs start 8 miles 4-11 to 4-21-55	290 tons 5800 lbs. **	$ 10,000 $ .08 $ 1,250
E-65-23.7-8.7 T.O. to 7.6 Sub-lat 1.3 Sub-lat 2.9	40 cfs start 12.7 4-11 to 4-20-56	280 tons 6000 lbs. **	$ 10,000 $ .10 $ 789

* Turn-out structure of upper end of lateral.

** Data common to all three trials: Soil type -- loess; Mixing method -- multiple jet; Mixing rate -- 2 to 4 sacks (100 lbs.) of bentonite per minute; Installation method -- slow ponding.

Thus, the above trials have included the use of (1) a high-swell Wyoming bentonite sediment, (2) a dispersing agent -- tetrasodium pyrophosphate, (3) the multiple jet mixer -- developed by the District, (4) the slow ponding method where the bentonite mixture is routed through many successive ponds, and (5) a clear water phase immediately in behind the milky sedimenting mixture.

In contrast to the above procedures, and as a matter of active interest in the planning of the current development work in the E-65 area, the procedures followed in other areas have varied from the E-65 procedures. Some of the differences in procedure reflect differing canal conditions of pervious soil and operation between the E-65 area and the other areas. However, some of the differences represent possible changes in procedure that should be evaluated as to applicability in the E-65 area.

For example, the bentonite sedimenting method that has been included in the Wyoming ASC Handbook for 1958 (USDA cost sharing program for conservation practices) does not require the use of a dispersing agent but does require harrowing of the canal bottom and sides during the bentonite phase. However, in the Wyoming method only limited sections of canal are treated from each mix point -- usually one or two ponds only.

Thus, as a general introduction into the current research and development program in the E-65 area, each major step in the bentonite sedimenting method will be briefly discussed. The conclusions resulting from the past trial work in the E-65 area will be very briefly summarized and those features emphasized where additional studies or evaluation work are needed.

Limitations of Method

In the E-65 system, seepage is the major problem; therefore, the conditions are, for the most part, favorable for the use of the bentonite sedimenting method of sealing the laterals. However, it should be recognized that the sedimenting method has certain limitations. It cannot control and the results may be affected adversely by additional canal problems, such as:

1. Active canal bank or bed erosion.
2. Severe sand bar movement on canal bed.
3. Heavy growths of bank or aquatic weeds.
4. Intense infestation of burrowing animals.

Perhaps studies should be initiated regarding special provisions that could be included in the sedimenting procedures for control of some of the above problems -- such as, for example, the crayfish problem found in some of the E-65 laterals. However, in general it may be assumed that the severe problems -- especially the erosional problems -- must be corrected or controlled separately and before the sediment sealing work is started.

Preliminary Preparations

The main objective of this first step in the sealing work is to prepare the lateral bed and banks for optimum entry and retention in depth of the bentonite clay. Thus, any maintenance work that is required, such as canal cleaning or removal of silt berms, should be accomplished before the sedimenting work. Since this cleaning work may tend to loosen the bed and bank materials, it is helpful if the cleaning is done just before the sedimenting. The bentonite has a better change of penetrating into the loosened materials.

In the E-65 area, canal silting is not a widespread or serious problem. Some restricted sections of lateral, however, are subject to relatively heavy silting. In those instances, it would be wise to over-excavate or over-clean the section so that subsequent cleaning operations would be less likely to disturb the bentonite sedimented zone.

When to Sediment

In deciding when to sediment, the question must be considered from both the standpoints of (1) canal operations, and (2) bentonite penetration and sealing possibilities.

In the E-65 area, the best time for sedimenting, as far as the canal operations are concerned, is usually in the spring just before the irrigation deliveries are started. If the weather is sufficiently dry at this time, the soil will be dry and cracked, the lateral preparations, such as weed burning and cleaning, can be easily accomplished, and favorable conditions exist for bentonite penetration and sealing of the canal bed and bank materials.

A not unusual spring in this area, however, is cold and snowy. Under these conditions the laterals can be full of snow and weeds up to the time when the water must be turned into the laterals. With this situation, the conditions are far from satisfactory for best sediment sealing results. If the canal bed and bank materials are frozen, sediment penetration is especially uncertain.

Fall conditions can be equally as uncertain. Because of the limited capacity and the heavy demands, water is usually run in the E-65 system until late in the fall or until the cold weather forces a shut-down. Thus, as in the spring, the time and weather element is quite often a serious problem for fall operations. Other serious sedimenting problems, such as the harmful effects of a canal dry-out immediately following the sedimenting, can also be introduced by operations in the fall.

In consideration of the above problems, it would seem wise to fully investigate the possibilities of sedimenting operations that could be run in during the first part of the irrigation season -- without unduly interfering with the normal water deliveries.

Selection of Sediment

After testing several potential sedimenting agents, including some local clay materials, the Wyoming bentonite was selected for the sedimenting work in the E-65 area. It was selected because it is in good supply, uniform in quality, relatively economical, and in a powdered form convenient for use in the common jet mixers.

Additional evaluation work on other potential sediments does not seem warranted at this time; however, it would be helpful to separate the sealing effects of the bentonite from those of the dispersing agent, or from those of any additional step in the procedure that seems worthy of evaluation, such as the harrowing procedure used in the Wyoming work.

It is interesting to note that the loessial soil in the E-65 area already contains a small proportion of bentonitic clay. However, the soil clay differs from the Wyoming bentonite in that it is a so-called calcium bentonite. The Wyoming bentonite is a sodium bentonite.

<u>Selection of Dispersant</u>

After testing several kinds of dispersants, it was decided that the polyphosphate agents were the best. Tetrasodium pyrophosphate was used as the dispersant in the E-65 work.

The dispersing agent is used to control the bentonite sediment drop-out during the ponding phase of the sedimenting process. This sediment flocculation or drop-out effect is caused by the excess calcium or hardness of the E-65 water. The hardness of the water varies from 200 to 300 ppm as $CaCO_3$. Water softening is the main action of the dispersing agent.

As a matter of research planning interest, the flocculation and bentonite settle-out problems are treated in a different manner in the Wyoming method of sedimenting. A mechanical method is used to stir the mixture and to break the surface filter cake that forms on the canal bottom and sides. Pulling a harrow along the bottom and sides during the bentonite ponding seems to effectively control the surface sealing problems.

In consideration of the nature of the loessial soil and the various problems of sediment sealing those soils, it would be helpful to evaluate the harrowing procedure -- both separately and in combination with the chemical dispersant.

Mixing Method

To accomplish the large scale mixing required in the E-65 trials, the District constructed a multiple jet mixer. The mixer, as designed by Mr. Johnson, will produce a uniform mixture, without appreciable lumps, at a rate up to 4 sacks (100 lbs each) of bentonite per minute.

The District's mixing equipment differs in some respects from the equipment used in other areas. Some of the other equipment is of simpler design, but in general the District's equipment produces a better lump-free mixture at higher mixing rates than the other equipment. However, in the planned development work, it would be advantageous to include also some evaluation and comparison testing of the other types of equipment -- especially the single jet type of mixer that is commonly used for mixing oil well drilling mud. The University project has the latter type of equipment available for loan and use in the evaluation work mentioned above.

Ponding Procedure

In the past District work, the bentonite sedimenting mixture was routed through successive ponds of the lateral sections being treated. Since the lateral slopes are relatively flat, adequate ponding was generally obtained by using the existing check structures. No temporary earth dams were required. Earth was used to mud-off the check structures for the ponding.

Since it required up to almost two weeks to route the sedimenting mixtures through the lateral sections being treated, an essentially stable mixture was a necessity. Severe flocculation problems could cause all of the clay sediment to drop out in the upper ponds, with no clay left in suspension to treat the lower ponds. With the dispersed bentonite type of operation, the sealing is concentrated in the leaky zones, with the bentonite in the water lost in each pond doing the sealing work.

In the alternative method where harrowing is substituted for chemical dispersion, more bentonite will probably be used, and the length of lateral treated from one mix point will have to be reduced from that possible with the dispersed bentonite method. However, where time is a serious factor, the ability to drop the bentonite out of suspension within a relatively short time and space could be utilized to a definite advantage.

Since it is advisable to keep water on the bentonite treated areas for at least a month or so after treatment, clear water has always been run in after the sedimenting mixture. Two methods have been used in this work: (1) the clear water is run directly into and following the bentonite mixture, and (2) each pond is drained of bentonite water and then immediately filled with clear water. The latter method seems to best fit the conditions found in the E-65 area.

It seems likely that the sedimenting materials and procedures used in the past work may be near optimum. However, if the present research program could segregate the relative effects of the various materials and procedures, the future lateral sealing work in the E-65 area could be more certainly guided than has been possible in the past. The information now at hand is somewhat clouded by a complex intermingling of factors and effects. As a consequence, the past evaluation methods have not produced conclusive and clear-cut results.

Evaluation Procedures

Various methods have been used to evaluate the results of the past bentonite sediment sealing development work in the E-65 area. As far as the District is concerned, however, the major evaluation procedure is one of measuring the changes in seepage loss rates produced by the sedimenting trials.

Since the water table is quite deep in the E-65 area, seep damage is not an evident problem -- at least not in the immediate area served by the lateral system. However, the seep damage in the adjacent areas below the E-65 area is undoubtedly contributed to by canal seepage and other return flows from the E-65 area, but definite information in this regard is not now available nor has it entered into the past evaluations.

Several different methods have been used in evaluating the canal seepage losses -- including ponding tests and analysis of delivery records. The results of the evaluations are summarized in Enclosure I of the

Appendix. Briefly stated, the results obtained by the various methods do not agree. The ponding tests seem to indicate considerable sealing effects from the past bentonite sediment sealing activities -- the delivery records show less favorable results.

As a result of the problems encountered in the above evaluations, it is now believed that the most satisfactory seepage evaluation will be produced by continuous inflow-outflow measurements at accurately rated stations in the lateral sections being treated. Since the seepage losses vary considerably throughout the irrigation season, continuous water loss records will provide the best evaluation information.

To obtain a better understanding of how the sealing action is produced, several supplemental evaluation methods have been attempted in the past work. For example, petrographic work was run by the Bureau of Reclamation on samples of the lateral bed and bank materials to determine if and how much bentonite was added during the sedimenting procedure. Results produced by this work, however, were somewhat indecisive because of factors, such as the following:

1. The bentonite naturally occurring in the loess cannot be readily distinguished and separated from the bentonite added by the sedimenting.

2. Because of the relatively large size, random scattering, and unpredictable depth of the holes -- loess tubes, crayfish holes, drying cracks, etc. -- in the loessial soil, there is no assurance that the field samples were taken at the same depths or even representative of the zones where the sealing action was concentrated.

Thus, the fundamental evaluations involving the use of soil sampling and testing techniques have serious shortcomings -- especially when the additional problem of limited research funds is also considered. However, as an exploratory and informational measure, it is believed that some limited soil sampling should be attempted at several representative sampling locations, both before and after any future sedimenting in the E-65 area. Of the various detection and evaluation methods available for use, the exchange capacity test -- including cation percentages -- would probably be best for testing of the soils obtained in the exploratory work.

Additions or losses in the total amount of clay in the soil can be detected from changes in the cation exchange capacity of samples collected before and after sedimenting. The exchangeable cation percentages are also important because of the sealing actions that can be produced by the sodium ion alone. For example, consider the sealing action produced in some clay soils by common table salt or NaCl in sealing farm ponds. In other words, a dispersed bentonite sedimenting mixture can produce several kinds of sealing actions, including the following:

1. Those produced by the sedimenting clay itself in plugging or in providing choke points in the inter-connected voids in the soil.

2. Those produced by the excess sodium in the sedimenting water -- including the dispersing, mobilizing, and swelling actions on the in-place soil clays.

In addition to the above actions, the excess sodium of a dispersed bentonite mixture could possibly produce localized and limited settlement effects in the loessial soils -- due to its dispersing action on the clay binder of the soil -- and thereby reduce the soil permeability. For this reason, and as an additional exploratory measure, density tests at the same sample points mentioned above should also be run, both before and after sedimenting. Since the dispersing effect of the sodium ion could also have an effect on the erosional stability of the lateral bed and banks, profile and cross-section information should also be collected at the sample points, before and after sedimenting.

It will be recognized that this exploratory sampling and testing could produce indecisive results -- because of the same factors previously mentioned.

Maintenance Procedures

Because of the past difficulties in obtaining accurate evaluation data for the treated sections of canal, definite information on the performance of the bentonite sealing and the required maintenance work is not available now. From the standpoint of future work, accurate and reasonably complete evaluation information -- including continuous seepage loss information -- is an absolute necessity. From this type of information, the life of the sealing action can be accurately charted, the maintenance problems delineated, and suitable corrective or maintenance procedures evolved.

RESEARCH OBJECTIVES

As a result of the past bentonite sedimenting work that has been accomplished in the E-65 area, a significant amount of useful sediment sealing information has been accumulated. However, to make full use of this information, answers to a number of fundamental questions are needed. The following fundamental questions may also be considered as research objectives in the current research program being supported by contract research funds from the Agricultural Research Service:

1. What immediate and long range effects would the following treatments or combinations of treatments have on the lateral seepage losses in the E-65 area, if applied as outlined below:

a. Harrowing of the lateral bottom and sides while water alone is ponded in the reach being treated.

b. Dispersant solution applied alone -- without bentonite and both with and without harrowing of the bottom and sides of the lateral during the ponding procedure.

c. Flocculating bentonite mixture applied -- without dispersant and both with and without harrowing during the ponding procedure.

d. Dispersed bentonite mixture applied -- with dispersant and both with and without harrowing during the ponding procedure.

2. What effects, adverse or otherwise, on the erosional stability of the lateral bed and banks will the following treatment or materials have:

a. Harrowing?

b. Dispersant?

c. Flocculated bentonite?

d. Dispersed bentonite?

3. What differences in sealing results will be obtained when the sedimenting mixture is run into:

a. A wet lateral that has been in operation for more than one month;

b. A dry lateral that has not been in operation for at least one month prior to the treatment.

4. What effect does the severe crayfish infestations found in some laterals of the E-65 system have on the following:

a. The initial penetration of the sedimenting mixture into the loessial materials.

b. The life of the sealing effect produced by the sediment sealing operations.

5. What are the cost to benefit relationships of the various sedimenting procedures and treatments mentioned above?

SUMMARY OF WORK COMPLETED IN NEW PROGRAM

Work completed in the current research program has consisted of (1) selection of site, and (2) detailed water loss measurements in the selected site.

The site selected for the detailed investigations is lateral 19.3 of the E 65 Main Lateral System. The soil conditions encountered on lateral 19.3 seem to be quite representative of the loess soil found throughout the E-65 area. The lateral is also representative of the other sub-laterals in the system -- from both the standpoints of lateral operation and lay-out.

Because of the basic importance of good water loss measurements, this phase of the investigation work was emphasized in the research activities for the summer of 1957. Enclosure 2 of the Appendix outlines in detail the results of the water loss measurements in lateral 19.3 during the summer of 1957. The water measuring system was devised and the report was prepared by Mr. A. W. Hall, hydraulic engineer for the District.

Briefly summarized, the water loss preparations and determinations have consisted of the following.

1. Division of the lateral into four sections with water measuring stations set up at the 19.3 turn-out, mile 1.6 check, mile 2.6 drop, mile 3.4 drop, and mile 4.4 check.

2. Installation of current meter bridges at each of the above stations. A Stevens type F recorder was installed at all stations, except at the turn-out where two recorders were needed.

3. Calibration and checking of the water measuring devices used on the field turn-outs on the lateral between mile 0 to mile 4.4.

4. Providing the patrolman on the lateral with a daily log form to be used in the detailed water loss measurements.

5. Accomplishing detailed water loss measurements from about the middle of July until the second week in October.

The detailed records accumulated in this work are included in Mr. Hall's report, Enclosure 2 of the Appendix. No water loss conclusions are made at this time, other than concluding that the measurements should be continued through the summer of 1958 before the trial sedimenting work is completed. The latter will probably be completed during the spring or early summer of 1959.

Originally, soil sampling work was to be accomplished in the lateral during October 1957. A trip was made for that purpose, but the lateral was too wet for satisfactory sampling.

TENTATIVE PLANS

Detailed plans concerning the remainder of the evaluation and development work in lateral 19.3 are now being worked out. Those portions of the work involving District people or construction remain to be checked out with Mr. Ted Johnson of the District. In addition, any major construction items involved in the sedimenting work will have to be cleared and approved by the District's Board of Directors. In a similar way, the activities involving University project people or facilities are subject to an administrative and technical review from both the University and the Agricultural Research Service.

The recommendations to be used in the considerations mentioned above are briefly outlined below:

1. Water loss measurements -- Because of the critical importance of accurate water loss measurements, the evaluation activities during the summer of 1958 are being concentrated on an extension of the water loss measurements started during July of 1957. The work in this season has already been started. It is recommended that it be continued until the water is shut off this fall -- with provisions to continue the measurements through the summers of 1959 and 1960.

2. General information -- To characterize the trial site, it is planned that the following items of general information will be obtained or compiled during the summer and fall of 1958 and, in some instances, during 1959:

a. Water quality -- In the past work, a limited number of water samples were collected at sporadic intervals. It is proposed that water sampling be started, just as soon as possible, and at monthly intervals during the remainder of this irrigation season and during the 1959 season. Two sample points are recommended -- one at the headgate on the lateral and the other at mile 4.4. The analyses of these samples should include: total dissolved solids, total suspended solids, and complete cations (Ca, Mg, Na, and K). It will be more convenient, and perhaps more accurate, if the District could have the analysis work on these samples run in Hastings rather than sending the samples to the University.

b. Map and survey information -- During the past work in the E-65 area, limited map and survey information has been obtained. Since the information may not be up-to-date nor detailed enough, it would be very helpful if the District could provide the University project with the following: (1) latest plan map of lateral 19.3, and (2) accurate profile and cross-section information on the lateral from mile 0 to mile 4.4, including locations and brief descriptions of structures, and an estimate of the wetted area and the water surface area at full capacity.

c. Ground water information -- Whether existing records can be used or a new system needs to be set up, definite provisions should be made so that the fluctuations of the ground water levels in the lateral 19.3 area can be observed -- both before and after the scheduled sedimenting trial in the lateral. Project personnel will be available for setting up the new system, if needed, but it would be best if the District could accomplish the periodic measurements, not already covered in an existing State or Federal program of ground water level measurements.

d. Soil map -- General information on the classification of soils in the E-65 area is needed. Any map or information that the District has in this regard will be appreciated.

3. Exploratory evaluations -- In an effort to better understand how the sealing action is produced, four locations for detailed exploratory sampling, testing, and observations are being planned for lateral 19.3 -- one location for each of the lateral sub-sections formed by the water measuring activities (see Enclosure 2 of the Appendix). Some of the details of the evaluation procedures will have to be worked out at the field sites but in general, the observations, sampling, and testing at each location should include the following:

a. When -- As a minimum, the detailed sampling at each location should be completed during the coming fall after water is out of the lateral, and again, with exactly the same procedures, during the next fall (1959) or before and after the sedimenting that is scheduled for next spring or early summer.

b. Evaluation control -- To provide valid comparisons, each location should be staked so that the before and after sampling of soil is done in different spots, but with each set of samples equally representative of the sampling locations. A checkerboard arrangement of sampling will probably be devised. Elevation controls will also be needed so that erosional or settlement effects can be detected.

c. Soil sampling -- As a minimum, the fall sampling at each of the four lateral locations should include: (1) three bottom samples, (2) two bank samples -- one in each bank, (3) each sample to a depth of three feet and segregated into four inch increments, and (4) density determinations during the sampling.

d. Soil testing -- It may be helpful to add other procedures during the laboratory evaluations, but at the present the testing of the above samples would include: (1) total cation exchange capacity, (2) exchangeable cation percentages, and (3) soluable cations. The testing will indicate an increase or decrease of clay in the soil increments testing. It will also indicate changes in the sodium ion content of the soils and the soil water.

e. Who -- All of the above work, except perhaps the survey work, will be accomplished by University project personnel. It would be helpful if the District could assist in the survey control work mentioned in (b) above.

4. Soil holes -- In the above exploratory evaluations, the effects of the soil holes have, to some extent, been ignored. Obviously, the large holes of a loessial soil, such as the loess tubes, crayfish burrows, and drying cracks, will be dominant factors in determining (1) where the major loss of lateral water occurs, and (2) where the major sediment sealing action must be concentrated. Thus, the sampling procedures as set up for the exploratory evaluation work could produce samples that are meaningless from the standpoints of (1) the actual holes that constitute the major loss zones, and (2) the soil depth or zones where the major void plugging or sediment sealing occurs. Therefore, before any exploratory sampling is started, a thorough exploration of the holes -- size, depth, frequency, etc. -- must be completed. Subsequent alteration of the planned exploratory evaluation procedures may then be needed. In addition, a better understanding of the nature of the holes in the loess soils in the laterals of the E-65 area could also result in some changes in the tentative sedimenting procedures as outlined in the following sections of this report.

5. Permeability testing -- Special equipment has been developed by the University project so that drive samples of the field site soils can be taken directly in a plastic permeameter tube. See Enclosure 3 and 4

of the Appendix for a drawing of the equipment. Thus, it might be helpful to run some preliminary sedimenting trials in the laboratory on relatively undisturbed samples of the loessial materal of lateral 19.3. However, in comparing the diameter of the soil sample (about 2.5 inches) with the size of the loess holes (range up to about 1.5 inches), it seems evident that the permeability of the permeameter soil may bear little relation to the over-all permeability of the soil in the lateral. It is recommended that this type of laboratory testing be held up until after the evaluation of the soil holes, as mentioned in (4) above, is completed.

6. Tentative trial procedures -- Upon completion of the preliminary evaluations previously outlined, some changes in procedure may be in order; however, it is believed that the tentative procedures, as outlined in TABLE II below, can be used as a satisfactory starting point in the District's final planning of the trial work in lateral 19.3 of the E-65 area. Since there are four sub-sections for which water loss measurements will be available, the number of procedure variations will be limited. It will not be possible to set up trial procedures to answer directly all of the questions previously outlined under RESEARCH OBJECTIVES. However, it is believed that the procedures as set up in TABLE II should provide answers to the more important questions -- all of the major procedure variation possibilities are included in TABLE II, but not all of the combinations of procedures.

TABLE II
RECOMMENDED TRIAL PROCEDURES

Section of Lateral 19.3	Recommended Procedures
T. O. to mi 1.6 check	Untreated section -- control to pick up natural variation in water losses on untreated section
Mi 1.6 to mi 2.6 drop	Flocculating bentonite mixture -- no dispersant but harrowing included during the ponding phase to combat tendency for surface seal only.
Mi 2.6 to mi 3.4 drop	Dispersant solution only -- no bentonite or harrowing. To show extent of sealing action produced by dispersant alone.
Mi 3.4 to mi 4.4 check	Dispersed bentonite mixture -- with dispersant but without harrowing. To show extent of sealing produced by normal dispersed mixture.

7. Discussion of tentative procedures -- Some of the more important considerations to be discussed in the District's final planning work are briefly outlined below:

a. Preliminary preparations -- It would be helpful if the trial section of lateral 19.3 from the headgate to mile 4.4 could be carefully inspected during the coming summer or fall. Any required maintenance, such as side sloping, canal cleaning, structure repair, riprapping, etc., should be completed during the coming winter and before water is turned in next spring.

b. When -- If weather conditions permit and the lateral is dry and in good condition for sedimenting, an installation time for the trail work in April, or just before the first water deliveries, would probably be best. If the conditions for sedimenting are not entirely satisfactory at that time, the trial work should be postponed until later in May or June. At this later time, the sedimenting trials would have to be set up on a flexible basis so that the work could be started on short notice and during a slack period in the normal irrigation water deliveries.

c. Mixing -- It is recommended that the flocculated bentonite mixing for the second pond be done with the University project mixer and air-slide hopper. The mixing for the dispersant only trial in the third pond and for the dispersed bentonite trial in the fourth pond should be done with the District's equipment.

d. Concentrations -- Preliminary mixture testing will be needed to determine the concentrations of bentonite and dispersant to be used in the various trials. However, as a general guide, the bentonite in the second and fourth ponds would probably be set up at one per cent (by weight of water). The dispersant requirements will have to be determined by trial and error -- enough to produce a stable bentonite mixture in the fourth pond, and probably near to complete water softening in the third pond.

e. Harrowing -- Because of the character of the loess soil, it is believed that harrowing of the lateral bottom and sides during the sediment ponding phase could be very beneficial. To evaluate its possibilities and effects, harrowing is recommended for use in the trial tentatively set up for the second pond. Its use with the flocculating bentonite mixture is appropriate for a number of reasons (i.e., supplemental mixing, breaking of surface coating, admixing the bentonite into the soil, etc.).

f. Mixture routing -- The flocculating bentonite mixture in the second pond should present no routing or wasting problems. By at least the third or fourth day, it should be completely dropped out of suspension and mixed into the lateral soil. The clear water, if any, that remains after the treatment in the second pond may be partially softened. Thus, its use in the third pond, where dispersant only is planned, should not produce any problems. In a similar way, the dispersant solution left, if any, after several days of ponding in the third pond could be utilized in the mixing operation for the fourth pond where dispersed bentonite is tentatively scheduled for use. The mixture left after several days of ponding in the fourth pond would have to be routed into downstream sections of lateral. This, however, should not be a problem, since there is available lateral space below mile 4.4.

APPENDIX

Enclosure 1

EVALUATION OF DELIVERY LOSS DATA IN REGARD TO BENTONITE SEDIMENTING TRIALS INSTALLED BY THE CENTRAL NEBRASKA PUBLIC POWER AND IRRIGATION DISTRICT

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INTRODUCTION

During the past three years, The Central Nebraska Public Power and Irrigation District has made trial sedimenting installations in three reaches of canal in the E-65 Main Lateral system. The development work was conducted cooperatively with the Civil Engineering Section of the Colorado A and M Research Foundation.

The purposes of this report are:

1. To analyze and discuss the results of the District's development work to date.

2. To make recommendations concerning the District's continuation of the development work.

EVALUATION PROCEDURES

Several methods of evaluating the results of the trial installations in the District area have been used. Most of the evaluation methods have involved water loss measurements, such as ponding and inflow-outflow tests in the treated reaches. The evaluation discussions in this report are restricted to the water loss measurements only.

In a previous report, dated February 21, 1956, the results of ponding tests run at the end of the 1954 and 1955 irrigation season were outlined and compared with losses obtained from the District's delivery records. Since the two methods give confli cting results, a more detailed study of the delivery records was planned.

The detailed study was accomplished by Mr. Orvin Marquardt, Irrigation Superintendent, at the Bertrand, Nebraska office. Daily diary records of the patrolmen for each study reach were used in place of the summary records used in the previous studies. The average losses for the months of June, July, August and September were determined. An adjusted seasonal loss for each reach was then determined from the average monthly loss. The study included the seasons of 1952 through 1956.

DISCUSSION OF DATA

Table I outlines the data obtained from the above detailed study. Figs. 1, 2 and 3 summarize graphically the data in Table I. As may be seen in Fig. 1, all three of the trials have produced some sealing effects and although the apparent sealing efficiency is very low on the initial trial, the succeeding trials have each shown a marked improvement in efficiency. However, as will be discussed later in this report, the sealing efficiency varies over a wide range with the type of seepage test used.

In an effort to determine the reliability of each set of test data, the average monthly delivery losses have been plotted in Fig. 2.

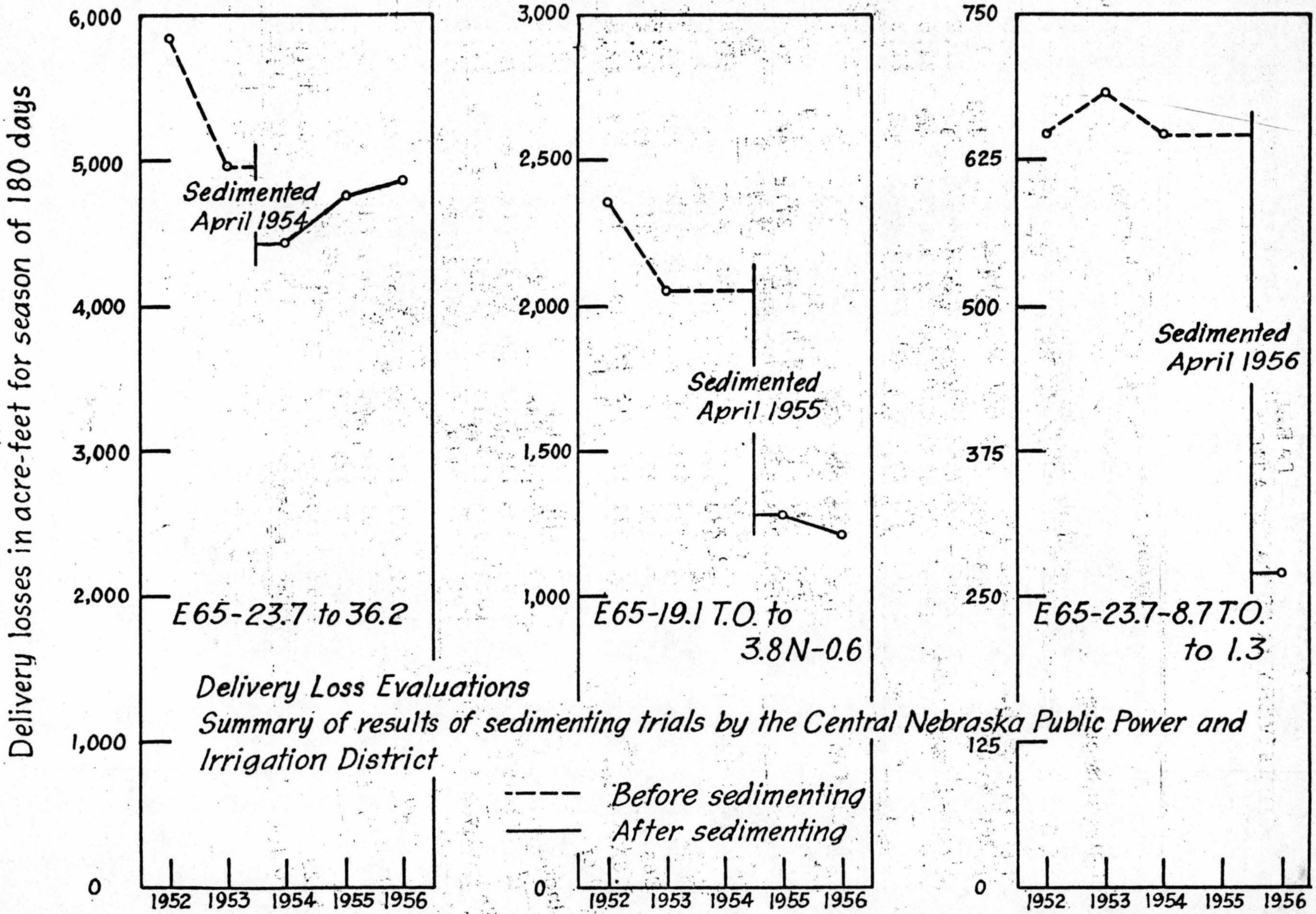
In order to eliminate the early and late season effects where the canals are kept full even though the deliveries may be quite variable, the delivery records for May and October were eliminated from consideration. This produced reasonably stable loss data for the last two trials (sub-lat. 19.1 and 8.7) but obviously the loss data for the first trial (23.7) still show considerable scatter -- especially for the months of June and September.

Fig. 3 is a plot of data obtained from several untreated reaches. Here again the losses on the E65-21.0 reach are fairly stable while the losses on the E65-23.7-9.8 reach show a random scattering.

TABLE I

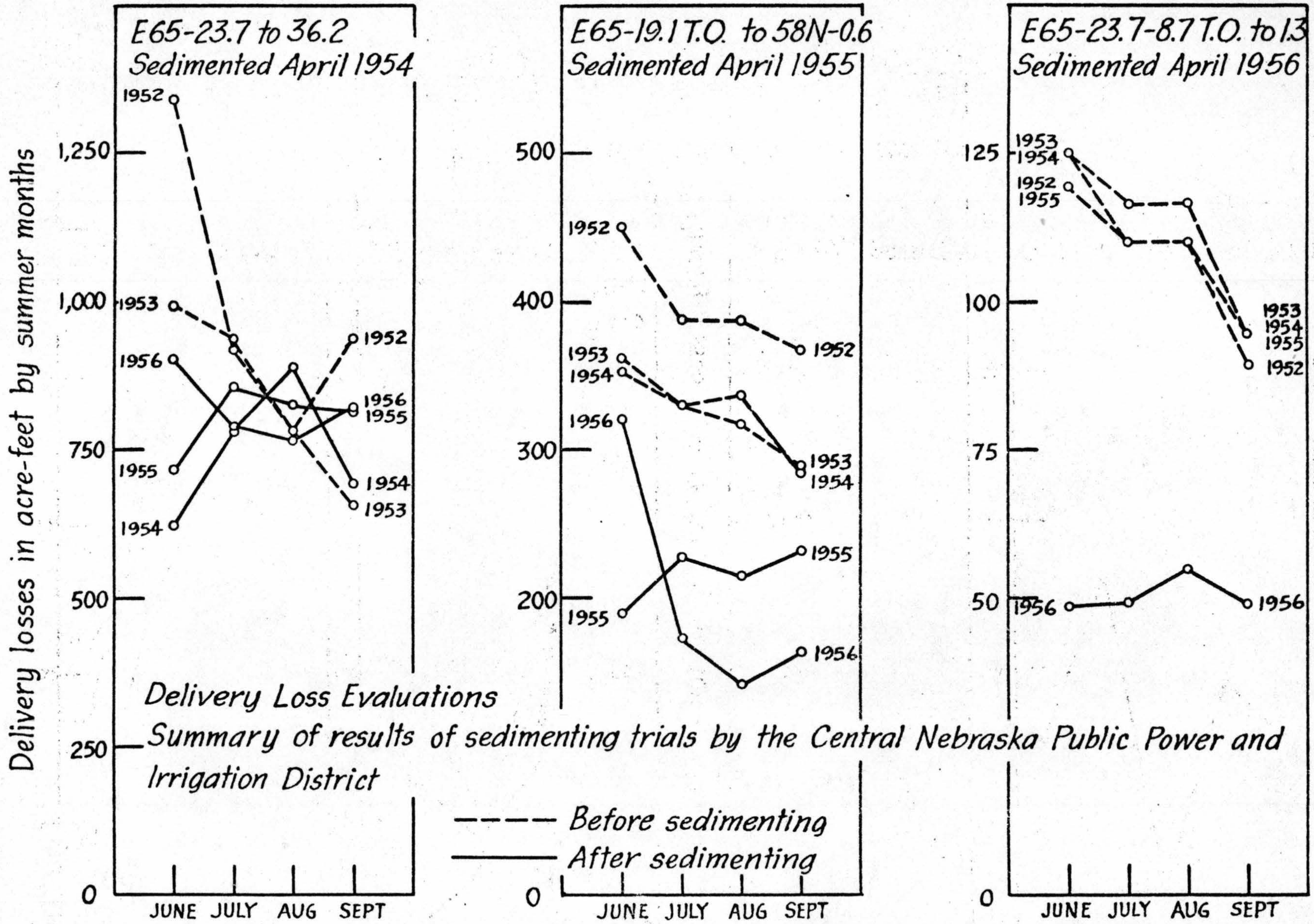
DELIVERY LOSS TABULATION - E-65 LATERAL SECTIONS

Lateral Section	Monthly Loss in Acre-Feet					Seasonal (180 day) Loss			
	Year	June	July	Aug	Sept	Div. A. F.	Loss A.F.	Loss A.F. /mi	Loss % of Div.
E65-23.7 to 36.2	1952	1342	927	780	939	20142	5850	468	29.0
100 cfs to 68 cfs	1953	998	939	780	653	22446	4986	399	22.2
Installed April 1954	1954	624	780	890	695	20466	4428	354	21.8
	1955	719	859	835	814	21060	4770	382	22.6
	1956	903	792	767	820	21708	4842	387	21.3
E65-21.0 to	1954	576	466	430	416	51102	2772	259	5.4
23.7 - 8.0	1955	636	411	387	440	44658	2772	259	6.2
	1956	778	546	411	392	49248	3132	293	6.4
E65-19.1 T.O. to	1952	451	387	387	368	9558	2358	368	24.7
5.8N-0.6	1953	362	331	319	291	10548	2106	329	20.0
60 cfs	1954	356	331	338	285	9468	2106	329	22.2
Installed April 1955	1955	190	227	215	232	8838	1278	200	14.5
	1956	321	172	141	166	10044	1206	188	12.0
E65-23.7 -8.7	1952	119	110	110	89	5922	648	498	10.9
T.O. to 1.3	1953	125	117	117	95	5886	684	526	11.6
40 cfs to 30 cfs	1954	125	110	110	95	6030	648	498	10.7
Installed April 1956	1955	119	110	110	95	5238	648	498	12.4
	1956	48	49	55	48	5382	288	222	5.3
E-65-23.7 - 9.8	1952	101	110	110	101	5526	648	432	11.7
T.O. to 1.5	1953	101	110	110	42	5166	540	360	10.4
32 cfs	1954	107	123	123	143	5598	756	504	13.5
	1955	119	129	117	36	5346	612	408	11.5
	1956	143	135	92	65	5490	648	432	11.8



Delivery Loss Evaluations
Summary of results of sedimenting trials by the Central Nebraska Public Power and Irrigation District

Figure 1



Delivery losses in acre-feet by summer months
E65-23.7 to 36.2
Sedimented April 1954
E65-19.1 T.O. to 58N-0.6
Sedimented April 1955
E65-23.7-8.7 T.O. to 1.3
Sedimented April 1956
1,250
1,000
750
500
250
0
500
400
300
200
0
125
100
75
50
0
1952
1953
1954
1955
1956
JUNE JULY AUG SEPT
Delivery Loss Evaluations
Summary of results of sedimenting trials by the Central Nebraska Public Power and Irrigation District
Before sedimenting
After sedimenting

Figure 2

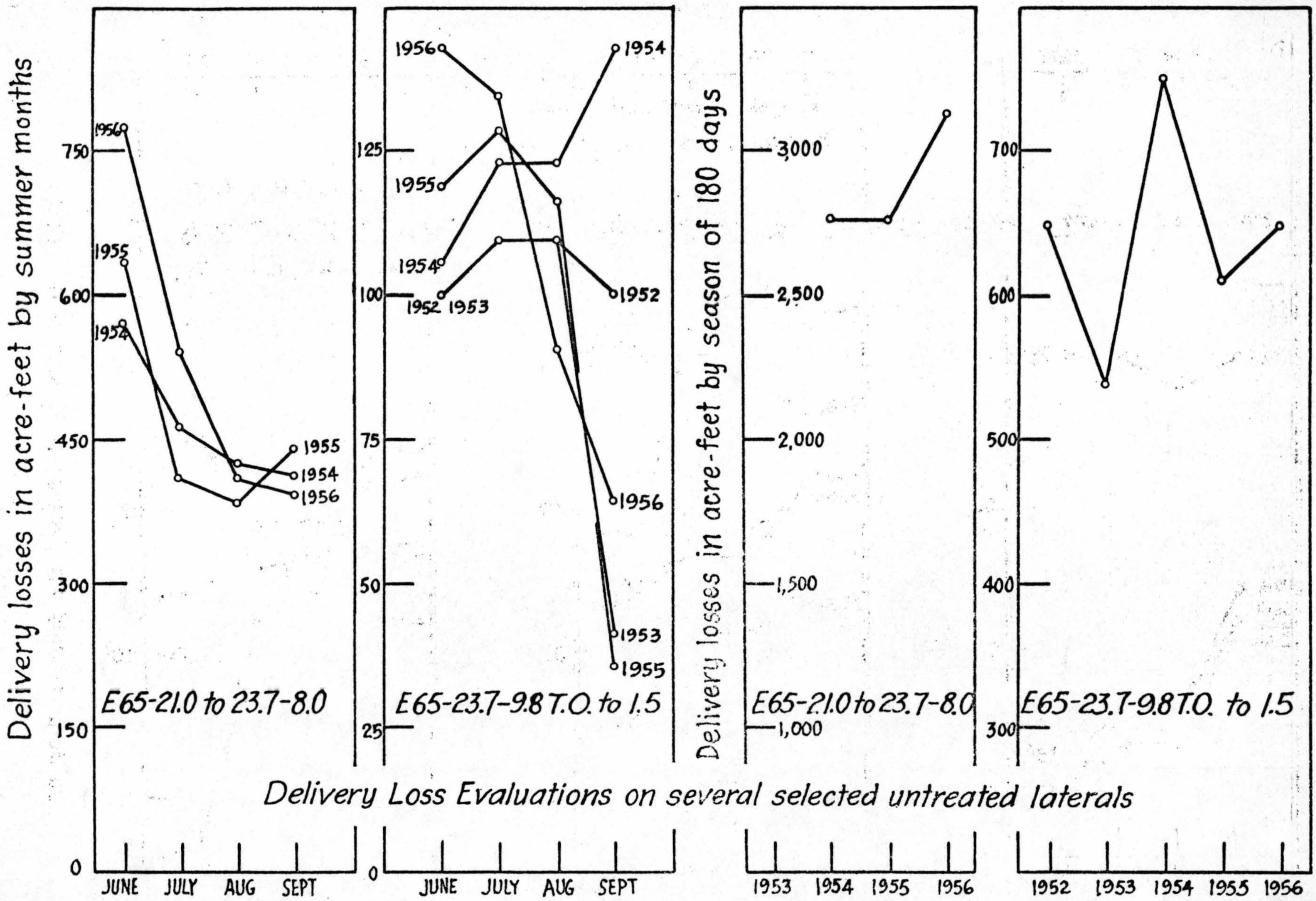

Delivery losses in acre-feet by summer months
E65-21.0 to 23.7-8.0
E65-23.7-9.8 T.O. to 1.5
Delivery losses in acre-feet by season of 180 days
E65-21.0 to 23.7-8.0
E65-23.7-9.8 T.O. to 1.5
Delivery Loss Evaluations on several selected untreated laterals
JUNE
JULY
AUG
SEPT
1952
1953
1954
1955
1956

Figure 3

COMPARISON WITH PONDING TEST DATA

Table II compares data obtained from three different methods of delivery loss determinations: (1) ponding -- falling head, (2) ponding -- constant head, and (3) detailed analysis of District delivery records. Table III compares the amount of water saved by the trial installations -- as indicated by (1) the ponding (falling head) tests and (2) the delivery records.

As may be seen in Tables II and III the sedimenting trials were successful if the results from the fall ponding (falling head) tests are considered. This type of test is commonly accepted as being the most accurate type of seepage measurement test. Obviously, however, the delivery loss and the constant head ponding data indicates that the results were somewhat less favorable.

The difference between the tests could indicate that the major loss was from the canal bank areas near the high water line; however, in considering the conditions in the field this seems unlikely. It seems more likely that the variations are due to the differences in the time of year and soil and water conditions common to each test method and, perhaps, due to other additional factors, such as evaporation, gate losses, operational losses, etc.

Since the delivery records cover the entire season, the results should give the best over-all picture of the delivery losses; provided the water measurements are accurate. During the 1956 season the District ran a number of spot checks to test the reliability of the measurements made by their patrolmen. This was accomplished by check tests involving the use in series of a Parshall flume, a rectangular weir and a Sparling flowmeter. In general, the patrolmen's measurements were found to be quite accurate -- usually within 2% of the measurements obtained by the check methods. It is recognized, however, that the accuracy of these records can change from time to time.

TABLE II

COMPARISON OF DELIVERY LOSS DATA

	1954		1955		1956			
Lateral Section	October Ponding Test Falling Head	September Delivery Records	October Ponding Test Falling Head	September Delivery Records	April Ponding Test Small Flow	June Delivery Records	October Ponding Test Small Flow	September Delivery Records
E65-23.7 to 36.2	2.6"/24hrs 0.32 cfs/mi	7.6"/24hrs 0.94 cfs/mi		8.9"/24hrs 1.10 cfs/mi		9.8"/24hrs 1.22 cfs/mi	8.9"/24hrs 1.10 cfs/mi	8.9"/24hrs 1.10 cfs/mi
(27.9 to 28.6)			3.1"/24hrs 0.38 cfs/mi		11.7"/24hrs 1.43 cfs/mi			
(28.6 to 31.3)			2.2"/24hrs 0.27 cfs/mi		13.5"/24hrs 1.67 cfs/mi			
E65-19.1 T.O. to 5.8N-0.6				5.5"/24hrs 0.61 cfs/mi		7.7"/24hrs 0.84 cfs/mi	3.8"/24hrs 0.42 cfs/mi	4.0"/24hrs 0.44 cfs/mi
(T.O. to 2.6)			1.4"/24hrs .16 cfs/mi		16.0"/24hrs 1.77 cfs/mi			
(2.6 to 3.2)			1.1"/24hrs .14 cfs/mi		5.4"/24hrs .67 cfs/mi			
(3.2 to 4.9)			1.6"/24hrs .18 cfs/mi		15.7"/24hrs 1.77 cfs/mi			
E-65-23.7-8.7 T.O. to 1.3			5.2"/24hrs .20 cfs/mi	32.3"/24hrs 1.28 cfs/mi		16.2"/24hrs 0.62 cfs/mi	16.2"/24hrs 0.62 cfs/mi	16.2"/24hrs 0.62 cfs/mi

TABLE III
ESTIMATED WATER SAVINGS

Lateral Section and Total Cost	Water Saved by Each Trial as Indicated by Ponding--Falling Head[1] Acre Feet	Ponding--Falling Head[1] Cost/A.F.	Delivery Records[2] Acre Feet	Delivery Records[2] Cost/A.F.
E-65 Main Lateral Mi 23.7 to 36.2 $15,000	10,600	$1.42 over 2 seasons	2,274[3]	$6.62 in 3 seasons
E-65-19.1 sub lat T.O. to Mi 5.8N-2.2 $10,000	3,600	$2.78 over 1 season	2,070[4]	$4.83 in 2 seasons
E-65-23.7-8.7 sub lat T.O. to Mi 7.6 1.3 -T.O. to Mi 3.8 2.9 -T.O. to Mi 1.3 $10,000	-	-	1,700[5]	$5.88 in 1 season

[1] Based on results outlined in February 21, 1956 report to District.

[2] Based on average of losses before and after sedimenting and as outlined in Table II.

[3] 758 acre feet per season x 3 = 2274 acre feet.

[4] 948 acre feet per season x 2 = 1896 acre feet in reach from T.O. to 5.8N-0.6, 1896 x (8-1)/6.4 = 2070 acre feet (adjusted for entire treated reach).

[5] 369 acre feet for 1956 season (T.O. to Mi 1.3, 369 x (12.7 - 6.7)/1.3 = 1700 acre feet (adjusted for entire 12.7 miles of treated lateral).

CONCLUSIONS AND RECOMMENDATIONS

In general, a measurable sealing effect has been produced in all three experimental trials. It is true that the sealing efficiency needs to be improved, but actually each trial has shown a marked improvement over the preceding trial. This seems quite favorable since the immediate objective of the work is to develop a low-cost method of reducing the District's serious distribution losses of over 50 per cent.

From the past results, the following conclusions may be drawn:

1. Mixing -- The multiple jet mixer, as developed by the District is entirely adequate - from the standpoint of both bentonite and dispersion and over-all cost.

2. Chemical dispersion -- After leaving the mixer, the bentonite mixture must be maintained in a dispersed condition for best sealing results in loess soils. Adequate chemical (polyphosphate) treatment has been helpful in this regard.

3. Dilution effects -- A clear water after-drive was used in the first two trials, but in the last trial the milky bentonite water was drained out of each pond before the clear water was run in. The latter procedure seems best. However, the clear water should be run into each treated reach just as soon as possible. Also it would be helpful to chemically soften the initial clear water after sedimenting.

4. Procedures after treatment -- Drying of the canal bottom immediately after bentonite treatment is to be avoided. Where possible, canals should be operated for several months after sedimenting under checked-up conditions in order to maintain maximum depths and minimum velocities of water.

It is concluded that a good start has been made and that the work has now developed to the point where significant advances -- both in technique and sealing results -- can be accomplished with considerably less time, effort and money than has been required in the past. It is, therefore, recommended that the District's development work be continued and concentrated on the following:

1. Additional but smaller tests -- Work should be started at new but small test sites where the soil and water conditions, before and after sedimenting, can be more closely tied-down than in the past trials. Continuous inflow-outflow water measurements are needed. Sites should be

selected where the delivery losses have been reasonably stable during the past five years.

2. Variation of treatment methods -- In past work the methods used have, in general, been quite similar for each trial. In the new trials the effects of several new variations in treatment procedure should be studied. This should include variations such as (a) use of chemical dispersant only, (b) use of smaller but repeated charges of bentonite mixtures, (c) use of varying concentrations of bentonite in water, and (d) use of flocculating agent in follow-up flow of clear water after sedimenting. Other project developments at the College and in other trial installations indicate that these variations could result in significant improvements.

Enclosure 2

Memo

To: Mr. Ted Johnson, Assistant Chief Engineer
From: Mr. A. W. Hall, Hydraulic Engineer
Subject: Losses in Lateral E65-19.3 November 15, 1957

This lateral was equipped with six stevens type F recorders during July 1957 for the purpose of attempting to determine the losses in 4.4 miles of the 19.3 lateral. Foot bridges were provided for current meter measurements at the main lateral 19.3 turnout from E-65 and at mile 1.6 check, mile 2.6 drop, mile 3.4 drop and mile 4.4 check.

The patrolman, Mr. Dean Houlden, was provided with a daily log form for the purpose of showing all changes in turnouts and changes at the checks and drops.

A reference point was established at each check and drop so the elevation of the top of stop logs could be determined with reference to the elevation of the water surface indicated by the recorders. There is good pondage at each of the check and drop stations so the drop and velocity of approach were very small with the small amount of water carried in this lateral.

The results of the records obtained were not as good as I had expected. Some of the irregular losses are due to change in channel storage but the most difficult thing is to determine the amount used through turnouts. We were not familiar with conditions along the lateral and I did not have time enough at the beginning of the run to make proper set up for the patrolman. I believe this experiment should be continued. We have learned the various characteristics of this lateral and future observation should be much more valuable than these records.

LOSSES
LATERAL E65-19.3
SECTION 0.0 TO MILE 1.6

Two type F stevens water level recorders were installed at the head of Lateral 19.3. One recorder indicated the water level in the main E-65 lateral and the other the water surface in lateral 19.3. The 19.3 lateral turnout is equipped with a 42 inch Calco meter gate. Flow into 19.3 lateral was determined by the gate opening and difference in head between the two water surfaces. Six current meter measurements were made at a gaging station about 100 feet below the headgate as follows.

Date	Gate Open. inches	Head inches	Meas. cfs	Table cfs	CA. Computed
7-30	8	15.5	15.1	15.1	1.65
8-21	5.25	21.0	10.6	12.4	1.004
8-28	5.25	23.0	11.7	12.9	1.053
9-4	5.25	18.25	10.2	11.5	1.032
9-11	7.0	11.75	11.0	11.9	1.38
9-26	9.0	8.0	11.6	11.9	1.782

The coefficient C in the standard orifice formula is a variable quantity for this type of gate. A rating table for the change in head was prepared using the computed value of CA for the various gate openings. The record of flow at this station was considered very good throughout the period of record.

PT. 0.3

This private turnout is a wooden gate with 14.5 inch open water way. The flow through the gate was determined from measurements made by the patrolman. The difference in head was determined by measuring from the top of the structure to the water surfaces above and below the gate and the gate opening was also by measurement. On September 26, I made a check measurement with a current meter. The difference in head was 8 inches and gate opening 5.5 inches. Computed from formula, the discharge was 2.0 cfs. and measurement 2.02. I visited this turnout several times and leakage here was practically zero, when the gate was closed.

PT. 1.1

This private turnout is a standard wooden gate with 14.5 inch open water way. I made a current meter measurement September 26th, with 4.75 inch gate opening and 9.0 inch head. Computed from formula discharge 2.19 and measurement 2.41. Measuring conditions were not good so I did not consider this as a very good check on computed flow.

Lt. 1.2

This turnout is equipped with standard wooden gate with 26.5 inch open water way. Current meter measurement on September 26, gate opening 5.62 inches and head 3.75 inches. Measurement 3.18 and computed flow 3.15. Very weedy lateral, considerable back water at the gate.

PT. 1.3

This is a standard 14.5 inch wooden turnout. I did not get a check measurement but noticed small seepage here practically all summer.

C 1.6

This check is a concrete bulkhead with flashboard gate in the center. The top flashboard has an angle iron fastened to the top to form a sharp weir crest. A stevens type F recorder was installed about twenty feet up-stream on the left bank and registers the water level above the check. The patrolman, Dean Houlden, measured down from the top of the steel flash-board guides to the top of the weir crest when a change was made. Check measurements were made by wading downstream from the weir with follow-results. The weir crest is 2.53 feet in width.

Date	Depth over weir, feet	Measured Discharge
7-30	1.10	9.6
9-4	0.38	2.25
9-4	0.64	4.83
9-11	1.04	9.14
9-11	0.79	6.27

From these measurements a rating table was prepared and head over the weir determined from the patrolman's report and water surface above the weir. The patrolman measured down from reference point on flashboard guide to top of weir crest.

0.0 TO 1.6 LOSSES

JULY

Patrol report with reference to Lt. 1.2 are very indefinite from July 26 to 30.

There was an interchange between pump and turnout at Lt. 1.2 from 26th to 31st and I could not determine how much was used. Then, on July 22, there was considerable pondage when 19 inches of flashboards were placed in c 1.6. The average loss during the remaining 8 days averages 1.1 cfs.

AUGUST

The first twelve days record indicates excessive losses possibly due to leakage at the turnouts. The average loss indicated is 3.68 cfs. The average for the other 19 days is 0.99 cfs. 766 acre feet entered the section and 641 acre feet were accounted for leaving a loss of 63 acre feet or 16.3%.

SEPTEMBER

I was unable to find a reason for excessive losses shown on September 5 and 25. The record indicates 698.6 acre feet entering the section and 603.0 acre feet accounted for showing 95.6 acre feet or 13.7% loss.

OCTOBER

This record shows 170.6 acre feet accounted for out of 185.8 entering the section and 15.2 acre feet or 8.2% loss. For August, September and October, there was 1414.6 acre feet accounted for out of 1650.4 entering the section on loss of 235.8 which is 14.3%.

CANAL SECTION 1.6 TO 2.6

This section of canal does not have any turnouts.

d 2.6

This station consists of a concrete overflow section or drop in the canal with rating station and recorder located about fifty feet upstream from the end of the concrete structure. The following current meter measurements established the rating table for this station.

Date	Gage Heighth	cfs Discharge
7-30	2.22	10.6
8-8	2.35	11.7
8-15	1.80	2.8
8-21	2.22	9.6
9-4	1.76	3.3
9-11	2.03	6.7
9-26	1.74	2.4

LOSSES-1.6 TO 2.6

Records at these stations considered good except July 18 to 23. For the period July 24th through October 7th excepting September 24th through 27th, the total entering the section was 1396.2 acre feet and the amount accounted for was 1300.4 showing a loss of 95.8 acre feet or 6.9% loss.

CANAL SECTION 2.6 - 3.4
Lt. 3.0

This is a standard turnout with 26.5 inch open waterway. Very weedy lateral and was used very little during the summer. I visited this location several times and found the lateral entirely dry, no leakage. Used patrolman's report of discharge.

Pt. 3.2

Standard wooden turnout with 14.5 inch open waterway. No check measurements made. Used patrolman's report of discharge.

Lt. 3.4

This is a standard wooden gate turnout with 26.5 inch free waterway. I did not get any check measurements. Used patrolman's record of discharge. There was small amount of leakage at this gate estimated at about 0.2 cfs. for few days after gate closed.

Pt. 3.4

This is standard wooden turnout with 14.5 inch free waterway. There was leakage here all summer. It was difficult to tell the amount because water was pumped from a well into the lateral most all the time.

d 3.4

This drop is in a wooden bulkhead with 2.94 ft wide flashboard gate in center, Stevens type F recorder was installed about 50 ft upstream from weir contraction tables. Two meter measurements were made but conditions were not favorable for good measurements. Head over weir were determined by measurement from reference point to top of weir crest and water surface shown at recorder.

LOSSES 2.6 TO 3.4

From period of record shown in totals there was 116.1 acre feet entered the section and 944.1 acre feet was accounted for indicating a loss of 172.0 acre feet or 15.4% loss. This would average 2.77 acre feet per 24 hours for the 62 days of record.

CANAL SECTION 3.4 to 4.4
Pt. 3.9, Pt. 4.2 and Pt. 4.3

These are standard wooden turnout gates with 14.5 clear waterway. Patrol discharge reports used.

Lt. 4.4

This is standard wood box with 26.5 inch clear waterway with discharge regulated by use of flashboards. Discharge was computed from weir formula by use of water surface determined from recorder and heighth of flashboards reported by patrolman. Levels were run to establish a measuring point at the gate so the heighths of flashboards were known with reference to the water surface at the recorder.

c. 4.4

This check is concrete structure with wooden flashboards 4.5 feet in width. A reference point on the steel guides was established so patrolman could measure down and give elevation of top of flashboards with reference to water surface shown by recorder which is located about 50 ft from the weir.

LOSSES 3.4 to 4.4
JULY

The seven days of record obtained show 24.1% losses for an average of 1.3 cfs per day.

AUGUST

August 12th, the loss shown apparently channel storage. No definite explanation for excessive loss on August 28th. August 22 to 25th, I believe incorrect amounts shown for turnouts. The twenty day record total indicates 14.4% loss or 1.15 cfs per day.

SEPTEMBER

On September 15, 16 and 17th, I believe there were some turnouts open but no indication on patrolman's log. The 27 day totals indicate 27.9% loss or loss of 1.38 cfs average per day.

OCTOBER

The seven day record during October shows 8.6% loss or average of 0.6 cfs per day.

SUMMARY
LOSSES IN CFS PER DAY PER MILE

Canal	July		August		September		October	
Section	Days	cfs	Days	cfs	Days	cfs	Days	cfs
0.0 to 1.6	8	0.69	19	0.63	30	1.00	7	0.68
1.6 to 2.6	8	0.90	31	0.53	26	0.67	7	1.02
2.6 to 3.4	7	1.92	23	1.91	26	1.21	7	0.68
3.4 to 4.4	7	1.33	26	0.91	27	1.38	7	0.60

The wetted perimeter of these sections of this lateral vary considerably and I believe we should run cross sections before the beginning of the irrigation season next year.

Cross sections would be valuable to Mr. Dirmeyer in his studies and would also give us a basis for comparison with other studies of losses from small laterals.

A. W. Hall (Signed)
A. W. Hall, Hydraulic Engineer

AWH:tf

THE CENTRAL NEBRASKA PUBLIC POWER AND IRRIGATION DISTRICT

Hastings, Nebraska

LOSS STUDY - LATERAL E65-19.3
From 0.0 to Mile 1.6 Values in cfs
July 1957

	0.0	Pt. 0.3	Pt. 1.1	Lt. 1.2	Pt. 1.3	C 1.6	Total Out	Loss		Precipitation
18	21.5					20.7	20.7	0.8		
19	22.2					22.0	22.0	0.2		
20	22.2					22.0	22.0	0.2		
21	21.9					22.0	22.0	0.2		
22	18.9					11.2	11.2	7.7	W.S. at 1.6	0.21
23	15.9	1.3	1.4			11.6	14.3	1.6	raised 1.06 ft	
24	15.8	1.9	2.1			9.7	13.7	2.1		
25	16.3	1.9	2.1		1.1	8.8	13.9	2.4		
26	16.2	1.1	2.1	1.3	1.7	8.7	14.9	1.3		0.92
27	15.6		0.8	?	0.6	9.8				
28	15.3			?		10.2				
29	15.3			?		10.3				
30	15.1			?		10.8				
31	14.5					11.6				

THE CENTRAL NEBRASKA PUBLIC POWER AND IRRIGATION DISTRICT

Hastings, Nebraska

LOSS STUDY - LATERAL E65-19.3
From 0.0 to Mile 1.6 Values in cfs
August 1957

	0.0	Pt. 0.3	Pt. 1.1	Lt. 1.2	Pt. 1.3	c 1.6	Total Out	Loss	Precip. Inches
1.	14.5					11.4	11.4	3.1	
2.	14.4					11.6	11.6	2.8	
3.	14.5					11.6	11.6	2.9	0.43
4.	15.1					11.0	11.0	4.1	
5.	15.4					11.3	11.3	4.1	
6.	15.3					11.4	11.4	3.9	
7.	15.4					11.4	11.4	4.0	
8.	15.4					11.4	11.4	4.0	0.15
9.	15.4					11.4	11.4	4.0	
10.	15.3					11.4	11.4	4.0	
11.	15.3					11.4	11.4	3.9	
12.	14.7					11.3	11.3	3.4	
13.	12.5	1.0	1.0			9.1	11.1	1.4	
14.	10.0	1.5	1.5		1.2	4.4	8.6	1.4	
15.	10.4	1.9	1.1	1.5	1.8	2.5	8.8	1.6	
16.	9.9	1.0	0	2.0	0.8	4.0	7.8	2.1	1.18
17.	9.6			2.2		5.7	7.9	1.7	
18.	9.6			2.2		5.7	7.9	1.7	
19.	9.5			2.2		5.6	7.8	1.7	
20.	10.0			0.7		8.2	8.9	1.1	.54
21.	10.8					10.0	10.0	0.8	
22.	10.8					10.0	10.0	0.8	
23.	10.8					10.4	10.4	0.4	.15
24.	11.2					10.9	10.9	0.3	
25.	11.5					10.9	10.9	0.6	
26.	11.5					10.9	10.9	0.6	
27.	11.5					10.9	10.9	0.6	
28.	11.5					10.9	10.9	0.6	
29.	11.5					11.1	11.1	0.4	.86
30.	11.5					10.9	10.9	0.6	
31.	11.4					10.9	10.9	0.5	
TOTAL	386.2	5.4	3.6	10.8	3.8	299.6	323.2	63.0	
A.FT.	766.0	10.7	7.1	21.4	7.5	594.2	641.0	125.0	3.31

THE CENTRAL NEBRASKA PUBLIC POWER AND IRRIGATION DISTRICT

Hastings, Nebraska

LOSS STUDY - LATERAL E-65-19.3
From 0.0 to Mile 1.6 Values in cfs
September 1957

	0.0	Pt. 0.3	Pt. 1.1	Lt. 1.2	Pt. 1.3	c 1.6	Total Out	Loss	Precip. Inches
1.	11.4					10.9	10.9	0.5	
2.	11.5					10.9	10.9	0.6	
3.	11.5					10.9	10.9	0.6	
4.	10.8	1.3	1.1			6.1	8.5	2.3	
5.	11.6	1.9	1.7		1.2	2.9	7.7	3.9	
6.	10.1	1.9	1.8		1.9	2.8	8.4	1.7	
7.	9.2	0.7	1.8	1.2	0.7	4.1	8.5	0.7	
8.	8.9		1.0	1.6		5.7	8.3	0.6	
9.	9.0			1.7		5.8	7.5	1.5	1.42
10.	9.0			1.8		5.9	7.7	1.3	
11.	9.3			1.9		6.0	7.9	1.4	
12.	11.2			0.6		9.6	10.2	1.0	
13.	13.0					11.8	11.8	2.2	0.17
14.	14.6					12.5	12.5	2.1	1.33
15.	12.9					11.2	11.2	1.7	
16.	12.9					11.2	11.2	1.7	
17.	12.9					11.2	11.2	1.7	
18.	14.3					11.6	11.6	2.7	
19.	13.6					12.0	12.0	1.6	.24
20.	13.5					12.0	12.0	1.5	
21.	13.4					11.9	11.9	1.5	
22.	13.4					11.9	11.9	1.5	
23.	11.9	1.2	1.1		1.2	6.1	9.6	2.3	
24.	11.7	2.0	1.8	1.4	2.0	1.8	9.0	2.7	
25.	11.9	2.0	1.9	2.1	0.7	1.9	8.6	3.3	
26.	11.4	2.2	2.1	1.1		2.4	8.8	2.6	
27.	10.9	0.9	0.9	1.3		6.8	9.9	1.0	
28.	10.8					9.8	9.8	1.0	
29.	12.4					11.2	11.2	1.2	
30.	13.2					12.4	12.4	0.8	
31.									
TOTAL	352.2	14.1	15.2	15.7	7.7	251.3	304.0	48.2	
A.FT.	698.6	28.0	30.1	31.1	15.3	498.4	603.0	95.6	3.16

THE CENTRAL NEBRASKA PUBLIC POWER AND IRRIGATION DISTRICT

Hastings, Nebraska

LOSS STUDY - LATERAL E65-19.3
From 0.0 to Mile 1.6 Values in cfs
October 1957

	0.0	Pt. 0.3	Pt. 1.1	Lt. 1.2	Pt. 1.3	c. 1.6	Total Out	Loss	Precip. Inches
1.	13.3					12.3	12.3	1.0	
2.	13.4					12.3	12.3	1.1	
3.	13.6					12.3	12.3	1.3	
4.	13.1					12.3	12.3	1.8	
5.	13.3					12.3	12.3	1.0	
6.	13.2					12.5	12.5	0.7	
7.	13.8					12.0	12.0	0.8	0.30
TOTAL	93.7					86.0	86.0	7.7	0.30
A.FT.	185.8					170.6	170.6	15.2	

THE CENTRAL NEBRASKA PUBLIC POWER AND IRRIGATION DISTRICT

Hastings, Nebraska

LOSS STUDY - LATERAL E65-19.3
From Mile 1.6 to 2.6   Values in cfs

	July 1957			August 1957			September 1957		
	c. 1.6	d. 2.6	Loss	c. 1.6	d. 2.6	Loss	c. 1.6	d. 2.6	Loss
1.				11.4	10.2	1.2	10.9	9.9	1.0
2.				11.6	10.2	1.4	10.9	10.0	0.9
3.				11.6	10.2	1.4	10.9	10.0	0.9
4.				11.0	11.0	0.0	6.1	5.4	0.7
5.				11.3	11.2	0.1	2.9	2.9	0.0
6.				11.4	11.2	0.2	2.8	2.4	0.4
7.				11.4	11.3	0.1	4.1	3.3	0.8
8.				11.4	11.6	+0.2	5.7	5.0	0.7
9.				11.4	11.6	+0.2	5.8	5.0	0.8
10.				11.4	11.6	+0.2	5.9	5.2	0.7
11.				11.4	11.6	+0.2	6.0	6.3	+0.3
12.				11.3	10.4	0.9	9.6	9.1	0.5
13.				9.1	8.5	0.6	11.8	11.2	0.6
14.				4.4	5.4	+1.0	12.5	10.8	1.7
15.				2.5	2.6	+0.1	11.2	10.5	0.7
16.				4.0	3.5	0.5	11.2	10.5	0.7
17.				5.7	5.6	0.1	11.2	10.5	0.7
18.	20.7	14.5		5.7	5.3	0.4	11.6	10.5	1.1
19.	22.0	14.8		5.6	5.3	0.3	12.0	11.0	1.0
20.	22.0	14.0		8.2	8.5	+0.3	12.0	11.2	0.8
21.	22.0	15.1		10.0	9.3	0.7	11.9	11.2	0.7
22.	11.2	14.9		10.0	9.2	0.8	11.9	11.2	0.7
23.	11.6	11.8		10.4	9.2	1.2	6.1	6.1	0.0
24.	9.7	9.1	0.6	10.9	9.8	1.1			
25.	8.8	8.2	0.6	10.9	9.6	1.3			
26.	8.7	8.0	0.7	10.9	9.8	1.1			
27.	9.8	8.8	1.0	10.9	9.9	1.0			
28.	10.2	9.3	0.9	10.9	9.9	1.0	9.8	9.4	0.4
29.	10.3	9.3	1.0	11.1	9.9	1.2	11.2	11.0	0.2
30.	10.8	9.8	1.0	10.9	9.9	1.0	12.4	11.5	0.9
31.	11.6	10.2	1.4	10.9	9.8	1.1			
TOTAL	79.9	72.7	7.2	299.6	283.1	16.5	238.4	221.1	17.3
A.FT.	158.5	144.2	14.3	594.2	561.5	32.7	472.9	438.6	34.3

THE CENTRAL NEBRASKA PUBLIC POWER AND IRRIGATION DISTRICT

Hastings, Nebraska

LOSS STUDY - LATERAL E65-19.3

From Mile 1.6 to 2.6 Values in cfs

	October 1957		
	c.	d.	
	1.6	2.6	Loss
1.	12.3	11.5	0.8
2.	12.3	11.5	0.8
3.	12.3	11.3	1.0
4.	12.3	11.2	1.1
5.	12.3	11.2	1.1
6.	12.5	11.2	1.3
7.	12.0	10.8	1.2
TOTAL	86.0	78.7	7.3
A.FT.	170.6	156.1	14.5

THE CENTRAL NEBRASKA PUBLIC POWER AND IRRIGATION DISTRICT

Hastings, Nebraska

LOSS STUDY - LATERAL E65-19.3
From Mile 2.6 To 3.4
July 1957

	d. 2.6	Lt. 3,0	Pt. 3.2	Lt. 3.4	Pt. 3.4	d. 3.4	Total Out	Loss
18.	14.5					15.9	15.9	
19.	14.8					15.0	15.0	
20.	14.0							
21.	15.1							
22,	14.9							
23.	11.8					7.5	7.5	
24.	9.1				0.9	5.1	6.0	
25.	8.2				1.9	5.5	7.4	0.8
26.	8.0				1.1	4.2	5.3	2.7
27.	8.8		0.9			5.1	6.0	2.8
28.	9.3		1.6			5.1	6.7	2.6
29.	9.3		1.9	1.0		6.0	8.9	0.4
30.	9.8	1.7	0.6	1.0		5.7	9.0	0.8
31.	10.2	2.5				7.0	9.5	0.7
TOTAL	63.6	4.2	5.0	2.0	3.0	38.6	52.8	10.8
A. Ft.	126.1	8.3	9.9	4.0	6.0	76.6	104.8	21.3

(Totals are for July 25 to 31)

THE CENTRAL NEBRASKA PUBLIC POWER AND IRRIGATION DISTRICT

Hastings, Nebraska

LOSS STUDY - LATERAL E65-19.3
From Mile 2.6 to 3.4 Values in cfs
August 1957

	d 2.6	Lt. 3.0	Pt. 3.2	Lt. 3.4	Pt. 3.4	d 3.4	Total Out	Loss
1.	10.2	2.5		0.9		6.3	9.7	0.5
2.	10.2	0.8		2.1		7.1	10.0	0.2
3.	10.2			2.1		6.2	8.3	1.9
4.	11.0			2.1		7.1	9.2	1.8
5.	11.2			2.1		8.4	10.5	0.7
6.	11.2			2.1		8.5	10.6	0.6
7.	11.3			1.0		9.2	10.2	1.1
8.	11.6					9.2	9.2	2.4
9.	11.6					9.2	9.2	2.4
10.	11.6					9.2	9.2	2.4
11.	11.6					8.2	8.2	3.4
12.	10.4					9.2	9.2	2.2
13.	8.5							
14.	5.4					2.7	2.7	2.7
15.	2.6					1.6	1.6	1.0
16.	3.5					1.6	1.6	1.9
17.	5.6		0.9			1.5	2.4	3.2
18.	5.3		1.9			1.2	3.1	2.2
19.	5.3		1.7			0.5	2.2	3.1
20.	8.5		0.9			2.7	3.6	4.9
21.	9.3					3.1	3.1	6.2
22.	9.2					3.1	3.1	6.1
23.	9.2					4.0	4.0	5.2
24.	9.8					4.4	4.4	5.4
25.	9.6					5.0	5.0	4.6
26.	9.8					5.2	5.2	4.6
27.	9.9					5.2	5.2	4.7
28.	9.9					9.4	9.4	0.5
29.	9.9					9.3	9.3	0.6
30.	9.9					9.1	9.1	0.8
31.	9.8					9.1	9.1	0.7
TOTAL	199.3	3.3	4.5	12.4		143.8	164.0	35.3
A.FT.	395.3	6.5	8.9	24.6		285.2	325.2	70.1

Note: August 20-27 inclusive omitted from totals.

THE CENTRAL NEBRASKA PUBLIC POWER AND IRRIGATION DISTRICT

Hastings, Nebraska

LOSS STUDY - LATERAL E65-19.3

From Mile 2.6 to 3.4 Values in cfs

September 1957

	d 2.6	Lt. 3.0	Pt. 3.2	Lt. 3.4	Pt. 3.4	d 3.4	Total Out	Loss
1.	9.9					9.4	9.4	0.5
2.	10.0					9.4	9.4	0.6
3.	10.0					9.5	9.5	0.5
4.	5.4					5.2	5.2	0.2
5.	2.9					2.4	2.4	0.5
6.	2.4					1.0	1.0	1.4
7.	3.3					1.4	1.4	1.9
8.	5.0		1.1			1.4	2.5	2.5
9.	5.0		1.7			1.3	3.0	2.0
10.	5.2		0.9	1.8		0.9	3.6	1.6
11.	6.3		0.5	2.8		2.2	5.5	0.8
12.	9.1			2.3		3.9	6.2	2.9
13.	11.2			1.9		5.3	7.2	4.0
14.	10.8			2.0		6.2	8.2	2.6
15.	10.5			1.0		8.0	9.0	1.5
16.	10.5					8.8	8.8	1.7
17.	10.5					9.8	9.8	0.7
18.	10.5					10.9	10.9	+0.4
19.	11.0					10.9	10.9	0.1
20.	11.2					10.9	10.9	0.3
21.	11.2					10.9	10.9	0.3
22.	11.2					10.9	10.9	0.3
23.	6.1					7.5	7.5	+1.4
24.						2.5	2.5	
25.						1.3	1.3	
26.						1.4	1.4	
27.					0.9	0.7	1.6	
28.	9.4		1.0		1.3	2.1	4.4	5.0
29.	11.0	1.1	1.8		1.4	2.4	6.7	4.3
30.	11.5	2.4	2.7		1.7	2.4	9.2	2.3
31.								
TOTAL	221.1	3.5	9.7	11.8	4.4	155.0	184.4	36.7
A.FT.	438.6	6.9	19.2	23.4	8.7	307.4	365.6	73.0

Note: September 24-27 omitted from totals.

THE CENTRAL NEBRASKA PUBLIC POWER AND IRRIGATION DISTRICT

Hastings, Nebraska

LOSS STUDY - LATERAL E65-19.3
From Mile 3.4 to 4.4 Values in cfs
July 1957

	d. 3.4	Pt. 3.9	Pt. 4.2	Pt. 4.3	Lt. 4.4	c. 4.4	Total Out	Loss
25.	5.5					3.0	3.0	2.5
26.	4.2					2.6	2.6	1.6
27.	5.1			1.0		3.1	4.1	1.0
28.	5.1			1.5		3.2	4.7	0.4
29.	6.0			1.5		2.3	3.8	2.2
30.	5.7	1.0		1.5		1.5	4.0	1.7
31.	7.0	1.5		1.5	1.7	2.4	7.1	+0.1
TOTAL	38.6	2.5		7.0	1.7	18.1	29.3	9.3
A. FT	76.6	4.9		13.9	3.4	35.9	58.1	18.5

LOSS STUDY - LATERAL E65-19.3
From Mile 2.6 to 3.4 Values in cfs
October 1957

	d. 2.6	Lt. 3.0	Pt. 3.2	Lt. 3.4	Pt. 3.4	d. 3.4	Total Out	Loss
1.	11.5	2.5	1.4			3.7	7.6	3.9
2.	11.5	3.0	2.7			6.4	12.1	+0.6
3.	11.3	3.2	1.4			6.8	11.4	+0.1
4.	11.2	3.2				6.2	9.4	1.8
5.	11.2	3.2				7.5	10.7	0.5
6.	11.2	3.2				9.5	12.7	+1.5
7.	10.8	1.9				9.1	11.0	+0.2
TOTAL	78.7	20.2	5.5			49.2	74.9	3.8
A. FT.	156.1	40.0	10.9			97.6	148.5	7.6

THE CENTRAL NEBRASKA PUBLIC POWER AND IRRIGATION DISTRICT

Hastings, Nebraska

LOSS STUDY - LATERAL E65-19.3
From Mile 3.4 to 4.4 Values in cfs
August 1957

	d. 3.4	Pt. 3.9	Pt. 4.2	Pt. 4.3	Lt. 4.4	c. 4.4	Total Out	Loss
1.	6.3	1.5		0.4	4.2	0.5	6.6	+0.3
2.	7.1	1.0			4.5	0.6	6.1	1.0
3.	6.2				4.9	1.0	5.9	0.3
4.	7.1				5.1	1.1	6.2	0.9
5.	8.4				5.4	1.3	6.7	1.7
6.	8.5				4.7	1.7	6.4	2.1
7.	9.2				5.1	2.0	7.1	2.1
8.	9.2				7.1	2.0	9.1	0.1
9.	9.2				7.1	2.9	10.0	+0.8
10.	9.2				6.9	1.7	8.6	0.6
11.	9.2				6.4	1.7	8.1	1.1
12.	9.2				4.1	2.1	6.2	3.0
13.								
14.	2.7					2.7	2.7	0.0
15.	1.6					0.5	0.5	1.1
16.	1.6					0.6	0.6	1.0
17.	1.5					0.9	0.9	0.6
18.	1.2					0.2	0.2	1.0
19.	0.5					0.0	0.0	0.5
20.	2.7	1.0				0.0	1.0	1.7
21.	3.1	1.6				0.4	2.0	1.1
22.	3.1	1.6		1.5	1.8	0.0		
23.	4.0	1.6		2.3	3.0	0.0		
24.	4.4	0.8		2.3	3.7	0.0		
25.	5.0			0.8	4.6	0.3		
26.	5.2				5.5	0.9	6.4	+1.2
27.	5.2				5.2	1.0	6.2	+1.0
28.	9.4				4.5	1.9	6.4	3.0
29.	9.3				4.8	3.2	8.0	1.3
30.	9.1				4.6	3.2	7.8	1.3
31.	9.1				4.7	3.2	7.9	1.2
TOTAL	161.0	5.2		0.4	94.8	37.3	137.7	23.7
A. FT.	319.3	10.3		0.8	188.0	74.0	273.1	46.2

(August 22-25 omitted from totals)

THE CENTRAL NEBRASKA PUBLIC POWER AND IRRIGATION DISTRICT

Hastings, Nebraska

LOSS STUDY - LATERAL E65-19.3
From Mile 3.4 to 4.4 Values in cfs
September 1957

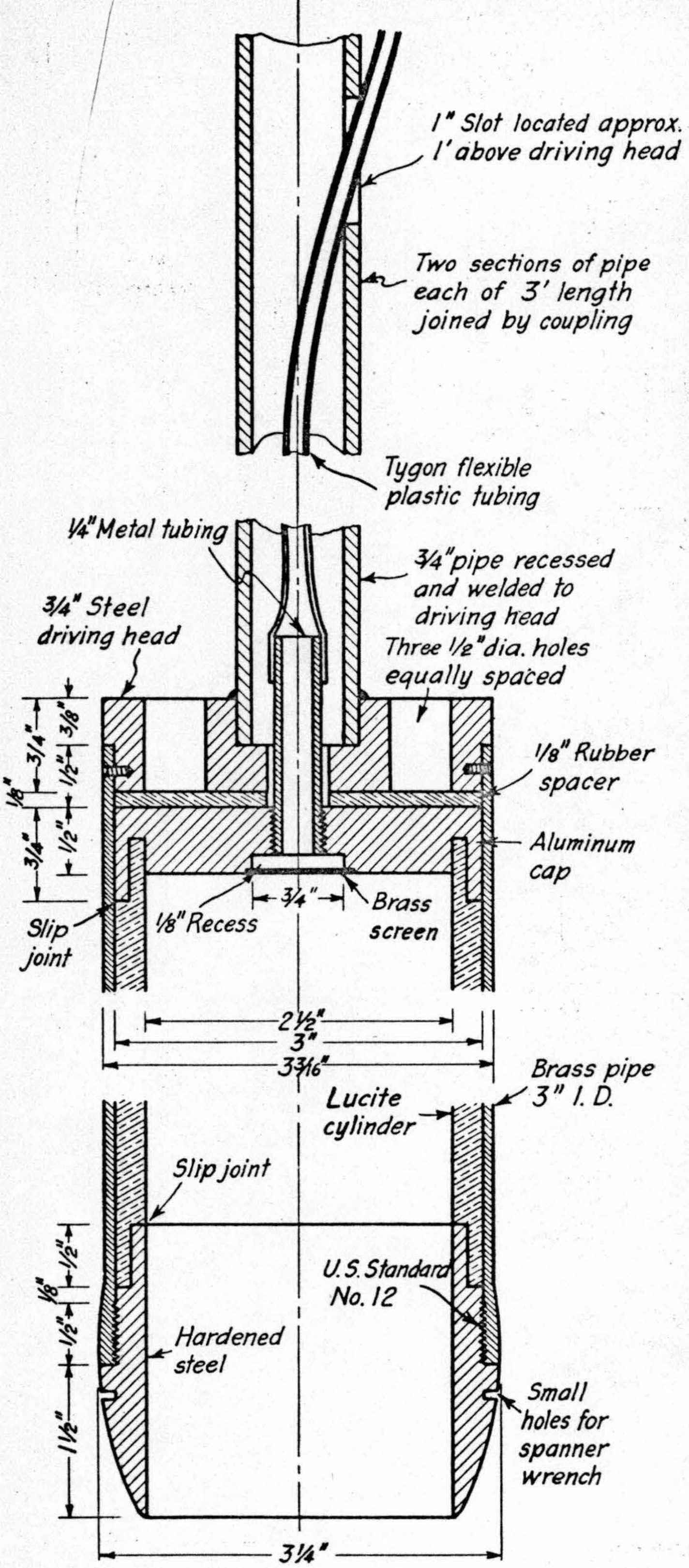
	d. 3.4	Pt. 3.9	Pt. 4.2	Pt. 4.3	Lt. 4.4	c. 4.4	Total Out	Loss
1.	9.4				8.7	0.0	8.7	0.7
2.	9.4				8.7	0.0	8.7	0.7
3.	9.5				8.7	0.0	8.7	0.8
4.	5.2				4.7	0.0	4.7	0.5
5.	2.4				1.1	0.0	1.1	1.3
6.	1.0				0.0	0.0	0.0	1.0
7.	1.4				0.0	0.5	0.5	0.9
8.	1.4				0.0	1.2	1.2	0.2
9.	1.3				0.0	0.0	0.0	1.3
10.	0.9				0.0	0.0	0.0	0.9
11.	2.2				0.0	0.0	0.0	2.2
12.	3.9	1.0			0.0	0.0	1.0	2.9
13.	5.3	1.5			1.6	0.0	3.1	2.2
14.	6.2	1.0			3.0	0.0	4.0	2.2
15.	8.0				2.2	0.5	2.7	5.3
16.	8.8				2.9	1.1	4.0	4.8
17.	9.8				6.2	0.0	6.2	3.6
18.	10.9				9.1	0.0	9.1	1.8
19.	10.9				10.3	0.0	10.3	0.6
20.	10.9				10.4	0.0	10.4	0.5
21.	10.9				10.4	0.0	10.4	0.5
22.	10.9				10.4	0.0	10.4	0.5
23.	7.5				4.3	0.0	4.3	3.2
24.	2.5				0.0	0.0	0.0	2.5
25.	1.3				0.0	0.0	0.0	1.3
26.	1.4				0.0	0.0	0.0	1.4
27.	0.7				0.2	0.0	0.2	0.5
28.	2.1				0.0	0.0	0.0	2.1
29.	2.4				0.0	0.0	0.0	2.4
30.	2.4				0.0	0.0	0.0	2.4
31.								
TOTAL	134.3	3.5			91.6	1.7	96.8	37.5
		(September 15, 16 and 17 omitted from totals)						
A. FT.	266.4	6.9			181.7	3.4	192.0	74.4

THE CENTRAL NEBRASKA PUBLIC POWER AND IRRIGATION DISTRICT

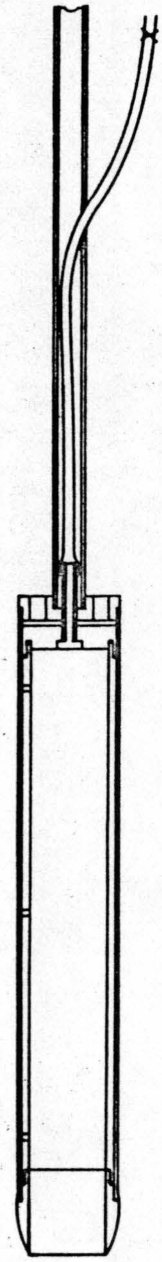
Hastings, Nebraska

LOSS STUDY - LATERAL E65-19.3
From Mile 3.4 to 4.4 Values in cfs
October 1957

	d. 3.4	Pt. 3.9	Pt. 4.2	Pt. 4.3	Lt. 4.4	c. 4.4	Total Out	Loss
1.	3.7				3.9	0.0	3.9	+0.2
2.	6.4				4.8	0.0	4.8	1.6
3.	6.8				6.2	0.0	6.2	0.6
4.	6.2				6.8	0.0	6.8	+0.6
5.	7.5				6.5	0.0	6.5	1.0
6.	9.5				6.4	2.0	8.4	1.1
7.	9.1				6.4	2.0	8.4	0.7
TOTAL	49.2				41.0	4.0	45.0	4.2
A. FT.	97.6				81.3	7.9	89.2	8.4



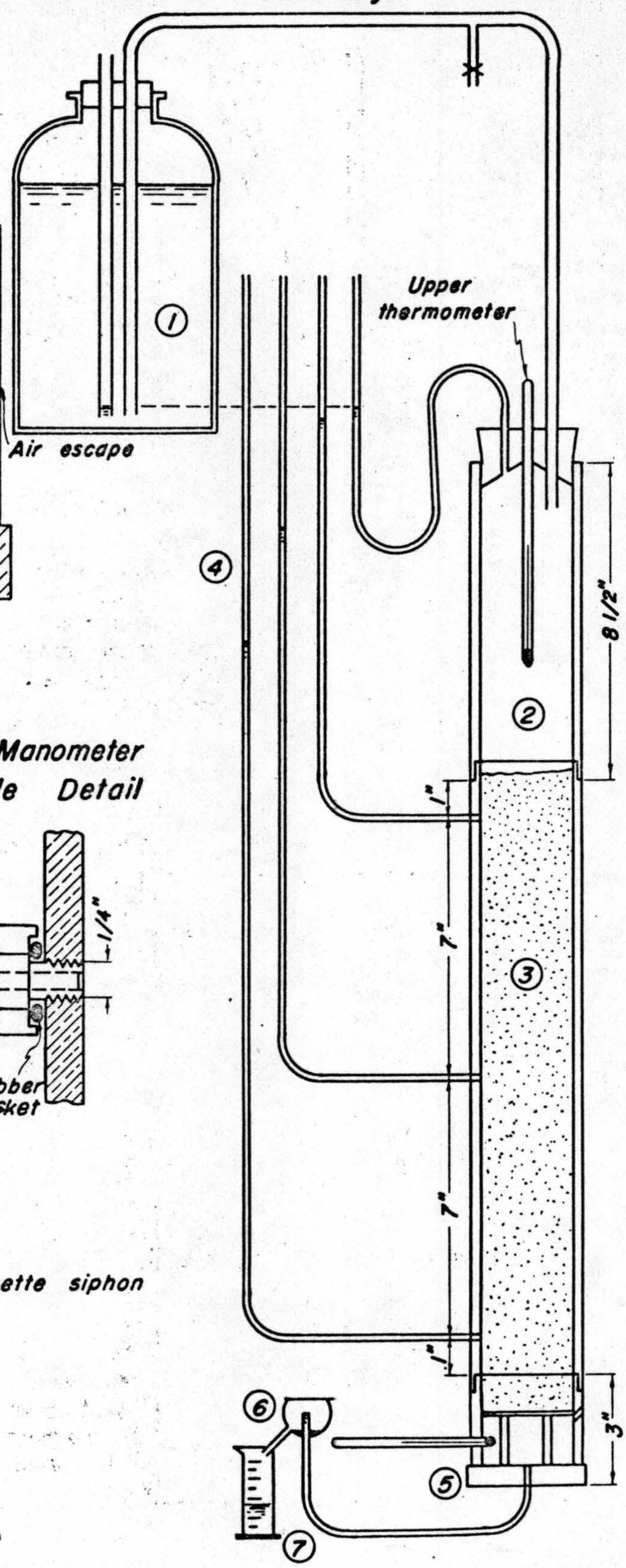
DETAIL



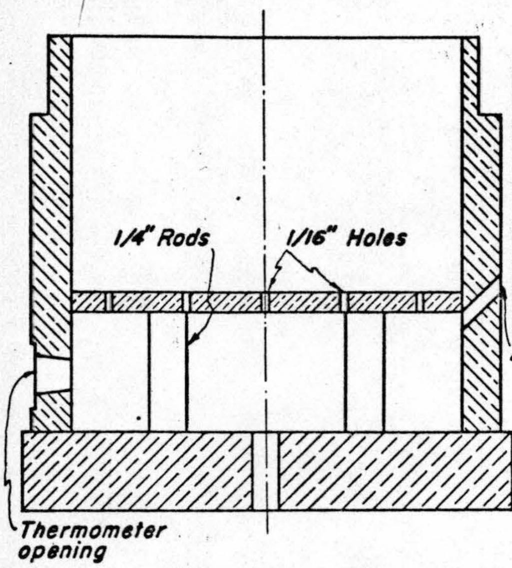
ASSEMBLY

ENCLOSURE 3 DRIVE SAMPLER

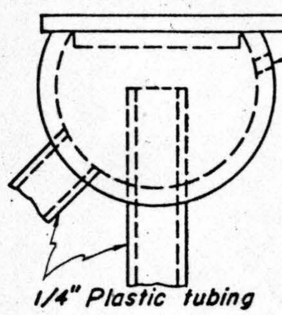
Assembly



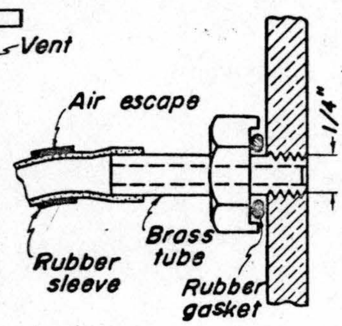
Filter Box



Tailwater Box



Manometer Hole Detail



① Water supply tank with marionette siphon to maintain constant head
② Lucite head reservoir
③ Lucite sample tube
④ Manometer bank
⑤ Filter box
⑥ Tailwater box
⑦ Cylinder for measuring effluent

ENCLOSURE 4 PERMEAMETER SETUP