TABLE OF CONTENTS
GREEN RIVER SUPPLY CANAL SEEPAGE STUDY REPORT

I. BACKGROUND
   A. Prior Study
   B. Nelson Engineering Learns of Polyacrylimydes
   C. Study Plan

II. PREPARATION AND POLYMER APPLICATION
   A. Hydraulic Conductivity Testing
   B. Proposed Lab Test Improvements
   C. Canal Cleaning
   D. Chemical Application
   E. Infusion of Polymer

III. DATA COLLECTION AND ANALYSIS
   A. Flow Measurements and Seepage Loss Measurements
   B. Monitoring Well Data Collection and Analysis
   C. Turbidity Measurements

IV. RESULTS, COSTS AND BENEFITS
   A. Reduction of Seepage
   B. Costs and Benefit/Cost Comparisons

V. CONCLUSIONS
   A. Effectiveness
   B. Cost Effectiveness
   C. Other Techniques
   D. Soils and Permeability Investigations
   E. Injection of Polymer
   F. Measurements

VI. APPENDIX
   A. Testing Protocol
   B. Chemical Suppliers
   C. Testing Equipment
   D. Recorded Data
   E. Nelson Engineering Staff
I. BACKGROUND

A. Prior Study

On June 19, 2002, Nelson Engineering began work on a Level II Study of the Green River Supply Canal. The canal diverts from Pooles Slough (Green River) approximately 4.75 miles east of Daniel Junction, in western Wyoming. The canal follows the west bank of Green River several miles, then crosses a low divide into Soap Hole Basin, crosses Cottonwood Creek, terminating a few miles east of Big Piney, Wyoming. For a more detailed background on the area, climate, geology, and operation of the canal, the reader is referred to “Green River Supply Canal Report, Phase 1,” November 2003, Nelson Engineering. By the fall of 2003, Nelson Engineering had completed inventory of the canal, identifying problems and had conducted three meetings with the canal district. Among other findings were three areas of major seepage loss that occurred in the Soap Hole Basin. A measure of the quantity of seepage loss was obtained via gauging of canal flow during the summer of 2003. The canal in the Soap Hole Basin is shown on Figure 1, which is a map of the area. On the map, and as herein referred to, the seepage reaches are numbered 1, 2, and 3. The beginning of seepage reach 1 is 1-1 and its end is 1-2. The beginning of reach 2 is 2-1 and its end is 2-2, etc. An important characteristic of the three reaches is that there are no diversions of water between the beginning, 1-1, and the very end, 3-2. Therefore, water flowing at 1-1 minus loss equals water flowing at 3-2.

B. Nelson Engineering Learns of Polyacrylamides

In the spring of 2003, Frank Grimes, vice president of Nelson Engineering, attended a meeting of irrigators, water resource persons and Natural Resource Conservation Service employees in Nebraska. At the meeting, he learned of the use of polyacrylamides (polymer) as a means of reducing seepage from canals. In theory, the polyacrylamide causes a tightly bonded film of flocculent to form on the canal bottom and thus reduces water penetration through the bottom. Upon his return, Frank obtained additional research materials and
discussed the idea with others in Nelson Engineering. It appeared that the idea had had very limited trial in Wyoming. According to all findings, the method was by far less expensive than any other method of reducing seepage. Several factors seemed clear:

- The method should be tested on a typical Wyoming canal.
- The tests should be varied in method of application per manufacturer’s recommendation.
- The results should be measurable enough to give quantitative results.
- Costs should be documented and equated to benefits.
- The three seepage reaches on GRSC presented an ideal testing ground.

In the fall of 2003, the GRSC irrigation district and Nelson Engineering applied for WWDC funding for a test project.

C. Study Plan

The initial study plan is described in this section. Although the plan was largely implemented as stated here, adjustments were made during the course of the study as more information was obtained from the study. In particular, the unexpectedly low turbidity levels found in the study reach after spring run-off did not allow conduct of the infusion testing in Reach 1 to proceed as planned. The primary problem was that supplier of the “biscuit” form of the polymer did not supply the product in this form in time to apply the product during the spring run off period when high turbidity levels occurred in the canal.

The study plan was to utilize a section of the Green River Supply Canal previously identified as seepage areas to test the efficacy of anionic polyacrylamides as a canal sealant. The field study would evaluate polymer applied using different protocols in different reaches. Testing protocols would differ by utilizing more than one polymer compound, utilizing higher and lower application rates, and in the method of polymer application (in solution, hyrdomulching).
Three test reaches in the Soap Hole Basin were used for the study. The sections consisted of reaches numbered #1 to #3 with #1 from upstream to downstream, as shown on the project map (Figure 1). The reaches were identified in the WWDC Level II study performed in 2002 and 2003 as reaches with high seepage losses. Seepage loss rates in these areas were measured for the Level II study. This data forms the baseline with which post polymer application seepage rates could be compared.

Differing test protocols were to be used in each seepage reach. Initial polymer applications would be surficial in reaches #2 and #3. An infusion of polymer into canal flow would be used in reach #1.

Reach #1

Sealing effectiveness testing in this reach was planned to utilize both CIBA and Exacto products (see Appendix B) in an uncleaned section of canal with sediment deposition and vegetated banks. Polymers in the form of pellets, blocks, and liquid would be immersed in the canal at a predetermined rate. The point of insertion into the canal in this reach was immediately upstream of the control structure below the Lateral #1 diversion (See Photo 1). This site provides a turbulent area for mixing immediately below the insertion point. Turbidity testing would be conducted downstream of the insertion point during polymer introduction to measure the effectiveness of polymer induced flocculation of sediment. The object of this exercise was to ascertain the optimal polymer dose rate (dose rate was to be directly related to the surface area of the blocks placed in the canal or by drip rate) using a portable turbidity meter in the field.

A program of testing to determine polymer dosing rates using sediment laden canal water collected in jars was also planned. Jar testing consists of measuring the flocculating abilities of polymer at differing concentrations using turbid water. The turbid water would be created by suspending the fraction passing the #200 sieve of soil samples taken from the canal bottom in the reach of interest.
To perform “jar” turbidity testing, it would be necessary to determine the dissolution rate of the blocks and the resultant concentration of polymer based on an expected canal flow. This would then be used to perform jar testing at differing concentrations of polymer to determine an optimal application rate. The study plan was to perform jar testing if in canal turbidity measurement proved unsuccessful.

*Reaches #2 and #3*

Testing Protocol would be the same for these reaches. The difference between the Sections is that prior to the irrigation season and the surface application of polymer, Section #3 would be cleaned and Section #2 would not be.

Initially, field-testing would consist of applying a solution of polymer to the canal bed and sides with a hydromulcher. Polymer would be applied in concentrations as determined by hydraulic conductivity testing conducted in the lab and on manufacturers recommendations. Products from both Ciba and Exacto would be used in the hydromulching solution, Exacto in Section 2 and Ciba in Section 3. Product selection and application rates would be determined by the results of the seal testing and per manufacturer’s recommendations. Seal testing would be conducted in late April.

If visible seeps or gross area seepage were observed along Sections #2 or #3 during the irrigation season, additional polymer applications would be conducted. In-season polymer applications would then be conducted by infusing polymer into the canal using immersed solid blocks or by liquid drip injection (as in reach #1). Test protocol specifics for in season applications would be determined at the time of application.
II. PREPARATION AND POLYMER APPLICATION

A. Hydraulic Conductivity Testing

A program of laboratory testing was implemented to determine the optimal amount and the effectiveness of the two different polymers sprayed on the canal bottom of reaches 2 and 3. The testing consisted of performing Modified Falling Head Hydraulic Conductivity (MFHHC) tests on undisturbed soil samples from the canal bottom. The hydraulic conductivity tests were intended to replicate the seepage through the soil column of the bottom of the canal within the two reaches studied. Tests were conducted in general conformance with “Testing Protocol” in Appendix A.

The test specimens were soil samples obtained by driving sections of four-inch diameter pipe into the canal bottom or bank approximately ten inches. Ten of these samples in total were collected in various sections of all three seepage reaches. Soil types in the samples were visually classified according to the Unified Soils Classification system. Soil types varied within each reach as well as vertically within individual samples. Soils were sands, silty sands, silts, and silty clays. Soils types were consistent with the variable strata of the Wasatch Formation denoted in the geological investigation conducted for the canal study.

The samples were subjected to a standard falling head hydraulic conductivity test consisting of applying about one foot of initial head to the samples and measuring the head drop over several hours. First tests were performed on untreated soil, to obtain control data. Prior to the second test, the surface of the samples was treated with either an Exacto or CIBA polymer prepared in a concentration recommended by the manufacturer. During the control tests, six of the samples with high clay contents exhibited baseline hydraulic conductivity values of less than one foot per day. The baseline value was low enough that the application of polymer produced no discernible reduction in hydraulic conductivity in the samples. The effect of polymer on the remaining four samples was to
decrease hydraulic conductivity by a factor of two or more. These samples were composed primarily of silty sands and sands.

The four higher hydraulic conductivity samples were taken from the canal bank, the six samples with lower values from the canal bottom. Therefore, the primary avenue of seepage from the canal is likely in a lateral direction through the outside bank in areas where the dike was constructed of uncompacted silty sand and sand materials, not vertically through the canal bottom.

The Exacto polymer provided in liquid form was easier to mix and apply uniformly to the soil surface in a four-inch diameter tube, resulting in higher hydraulic conductivity reductions. The CIBA polymer was supplied in granular form and was difficult to mix to a uniform solution and then apply uniformly to the soil surface. The CIBA application had “drain holes” where the water was able to escape almost as quickly as if the polymer had not been added. The problem with uniform application of the CIBA product is likely an artifact of mixing small volumes of solution to the desired concentration for the lab, however some of the larger volumes mixed in the hydromulcher during field application were subject to the formation of fish-eyes. In general, the granular polymer supplied by CIBA required more labor and time to mix properly in both the laboratory and the field.

B. Proposed Lab Test Improvements

The hydraulic conductivity testing protocol utilized produced largely ambiguous and unsatisfactory results. The following suggestions for improved pre-application testing should be considered.

The use of small diameter cylindrical samples presented several problems during the hydraulic testing protocol. Proper draining of the sample tube bottoms proved to be problematic. Several methods were attempted to allow unrestricted flow out the bottom of the samples. Methods included geo-textiles and cheesecloth wrapped around the tube bottom and seating the samples in a bed of coarse sand. A combination of geo-textile and bedding sands was found to work best. Initially, the sample tubes were of sufficient
length to apply 2 to 3 feet of head across the sample, as is found in the canal. It was found that applying polymers to the soil surface uniformly through the longer tubes was impractical. Further trials showed that polymer could be applied relatively easily with a sample tube length of about 10 inches above the soil.

The problem of determining the efficacy of applying polymer to canal soils in the lab is a difficult one. Ideally, testing would be conducted on undisturbed soils from canal seepage areas using driving heads representative of canal depths. Practically, this is difficult to implement. Future testing efforts in the lab might include the incorporation of larger undisturbed sample diameters (PVC tubes or five-gallon buckets). The possibility of installing lysimeters composed of large diameter PVC pipe in the canal bottom on-site and measuring before and after seepage rates could provide a qualitative measure of polymer effectiveness prior to large-scale application.

In addition, neither the described testing, nor jar testing, can adequately allow for and consider the variable of water velocity within the canal. Moving water, by its nature, has a different relationship with ground surface than the static water of the described tests.

C. Canal Cleaning

On the advice of one of the chemical manufacturers, reach 3 of the canal was cleaned. A caterpillar track hoe was utilized and cleaning resulted in approximately 3:1 side slopes on each bank. Vegetation was removed and the bottom brought to fairly uniform grade. The canal was wide enough throughout reach 3 that it necessitated cleaning from each side (2 passes). Reach 3 is 1.45 miles long. Cleaning noticeably improved the operating characteristics of the reach. The reach crossed highway 89 twice. See Photo 2.
D. Chemical Application

*Hydromulching*

An Exacto Chemical Company product, see Appendix B, was applied by hydromulch applicator to reach 2. The product was furnished in liquid form of about the viscosity of heavy syrup and required extensive mixing to dilute to solution. The tank for the hydromulch applicator was 400 gallons, for which the manufacturers recommended polymer concentration was five pints per tank. Half of the polymer was added to a half-full tank and the mixture agitated for 10 to 20 minutes after which the tank was filled and the remainder added. The mixture was then agitated for an additional ten minutes. Water temperature, agitator style, and rate affect mix time, both manufacturers provided recommended agitation times for various water temperatures—the warmer the water, the shorter the mixing process. In the field, the above mentioned mixture times were a result of observing the uniformity of the solution in the tank. Water temperature was estimated to be in the range of 40 to 50 degrees. When the solution was observed to be satisfactorily mixed, i.e. uniformly viscous with no “fish eyes,” it was sprayed on to the canal using a standard
hydromulching nozzle in order to ensure a consistent coverage. The application process was a four-person job: a driver for the truck the hydromulcher is mounted on, a nozzle operator spraying the canal bottom, one person to carry the hose over any obstacles encountered along the canal bank, while the canal is being sprayed, and a fourth person refills the water truck. For the hydromulch unit used here, one-tank volume covers 300 to 350 feet of linear feet of canal averaging 20 feet wide. The spraying of one tank took from 20 to 30 minutes. Due to the narrow canal bank, a relatively small water truck must be used resulting in the need to refill every fourth or fifth load. Once the details were worked out, the application process went smoothly although it took much longer than anticipated. See Photo 3.

A Ciba Chemical Company product, see Appendix B, was applied by the same equipment to reach 3. The product was furnished in a granular form (small grains larger than table salt). The application rate was 7.5 lbs per tank as recommended by the
manufacturer. As with the Exacto chemical, the CIBA polymer was added to the tank and mixed in two stages. This product required about forty to forty-five minutes mix time to reduce to solution. After several batches, there was a build up of product in the mix tank and slimy globes were spit from the application nozzle, indicating that the adequate mixing was not taking place in the bottom of the tank. To clear the slime from the tank and to keep the pump from fouling, a full flush of the tank was required after three or four tankfulls. The granular product was more difficult to mix and required an estimated 25% more time per tank full than the Exacto product to apply. The canal bank in reach 3 was cleaned (as seen in Photo 4) making it much easier to uniformly cover the bank with the solution as well as keep the hose free of any obstacles. See Photo 4.
As the hydromulch operation was paid for on an hourly basis, the cost per acre of application is significantly affected by mixing time and time required flushing the tank. Therefore, all other factors being equal, an easily mixed liquid polymer is recommended. Availability of a water-source significantly affects costs, as the water truck time to fill and return impacts both trucking costs and can result in down time waiting for water to arrive. Ideally, the time for a water truck to fill and return to the site should be less than the time required to spray one section of canal so that no down time results from water filling operations.

E. Infusion of Polymer

*Flow Induced Polymer Introduction*

Two different forms of polymer, liquid in solution and a solid briquette or “biscuit,” were introduced into the canal after water was turned in. The primary injection point being the beginning of reach 1. The objective of a direct application is to settle any sediment suspended in the flow of the canal. Over time this will result in a layer of fine soil lining the bottom of the canal. Both products used were manufactured by Ciba.

On June 15th, the liquid polymer was dripped into the canal in several locations using a two-gallon container fitted with a stop-cock valve. Due to the consistency of the material, the flow rate of the valve was not consistent and would become plugged after 40 to 120 minutes. Initially the valve was opened to the maximum recommended flow of one-quarter gallon per minute. This dosage resulted in a visual drop in the turbidity of the canal.

On July 1st, we attempted to dilute the liquid polymer with water in order to add it at a lower concentration over a longer period of time. It was found that this material did not mix readily with the water in the dosing container, instead turning into a marshmallow consistency “goo.” After tedious mixing, this solution was added at lateral #1 and the turbidity was measured at station 1-1. The turbidity was found to be reduced by 50%
compared to measurements made throughout the irrigation season. Unmixed polymer was observed below the seepage reaches during this application. The fish-eye polymer was observed to dissolve slowly as it was conveyed down the canal. Polymer in solution is believed to stay in solution until the naturally occurring turbidity induced by canal flow is sufficient for flocculation to occur over the length of the canal.

The “biscuit” polymer was not received until the beginning of July, by which point the spring run off had ended. This results in a lack of sediment in the canal making any flocculation minimal. The “biscuits” were placed in a mesh bag and hung on the bridge located just below station 3-1 and at lateral #1. The velocity at station 3-1 was too low to dissolve any of the “biscuits” in any length of time. The structure located at the diversion of lateral #1 creates an area of turbid water with a velocity in excess of five feet per second. This is adequate to dissolve about 15 “biscuits” in a day or less. Each location had two mesh bags, which were filled at least two times per week. It is hard to tell if any flocculation occurred due to the low dosage rate and lack of turbidity in the water. However, the injection of polymer was effective in reducing seepage in reach #1 and no doubt assisted in reduction for reaches #2 and #3.
III. DATA COLLECTION AND ANALYSIS

During the spring and summer of 2004, Nelson Engineering collected flow, turbidity, and groundwater elevation data at selected locations along the GRSC in the Soap Hole Basin. The data obtained was then analyzed for correctness and clarity. The results of this analysis were utilized to determine the effect of polyacrylamide application on the seepage from the canal in the test reaches. The following sections summarize project data collection and analytical methodology.

A. Flow Measurements and Seepage Loss Measurements

Two methods for measuring flows were utilized; flow gauging and flow monitoring (see Appendix C for equipment description). Nelson Engineering conducted flow gauging on nine occasions from May 15 to July 30 of 2004. Flow monitoring stations were installed to provide a continuous record of flows at the upper (1-1) and lower (3-2) ends of the three seepage study reaches. Flow recorder data was used to provide an overall picture of the flow regime. Flow gauging data was used to determine seepage in the test reaches and thus to determine efficiency of polyacrylamide in the test reaches.

*Flow Recorder Data*

The flow monitoring stations consisted of a Stevens type A (see Appendix C) chart recorder and float installed in a stilling basin. In theory, the chart records the elevation of the float, measuring the stage of the canal continuously. During this study, both of the monitoring stations were subject to frequent paper jams and instances where the floats became stuck. Smaller gaps in the recorder flow data were usually caused by a mechanical problem that was fixed on the next field visit. The recorder installed at Station 1-1 recorded properly for the first week of monitoring and then suffered repeated breakdowns. The recorder at Station 1-1 was replaced in late June.
Rating curves were constructed from the flow gauging measurements at each station. However, due the unpredictability of day to day canal operations and inflows during snowmelt, the highest range of flows was not measured. Conversely, flow gauging did not capture the lowest range of flows that take place at the beginning and end of the irrigation season. Consequently, engineering judgement was used to extrapolate the rating curves for the highest and lowest range of flows. The average estimated error associated with the rating curves is ±5% within the range of flows gauged at each station. Extrapolated portions of the rating curves may have a higher error percentage. Given the estimated error of the flow gauging itself of 5%, we assumed a cumulative error of 10% or less of the calculated flows. Calculated flows from the flow recorders are shown in Figure 2.

*Flow Gauging*

Flow gauging was conducted using a current meter (see Appendix C) to measure canal flow at a given point. Reaches of the canal that had conditions reasonably close to uniform steady flow were selected at the top and bottom of each test section. Theoretically, an accuracy of plus or minus 5% can be achieved using this methodology under these conditions. The result is a one-time measure of flow quantity. A record of the dates and results of the flow gauging conducted is contained in Appendix D.

**B. Monitoring Well Data Collection and Analysis**

Monitoring wells were installed in six locations (two per reach) of the test area in the Soap Hole Basin. Monitoring wells consisted of 4” diameter perforated PVC pipes wrapped in geotextile to prevent sediment deposition in the well. All of the monitoring wells were constructed with a bottom depth of about 36”. Monitoring wells were placed down-gradient of the canal, at the beginning and end of each of the test reaches, in areas where surface water had been observed in the previous year. Data collected from the Monitoring Wells is shown in Table 3.1.
FIGURE 2
Green River Supply Canal
Seepage Reach Flow Data
Summer 2004

Figure 2
### TABLE 3.1

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Table 3.1: Monitoring Well Data Summer 2004—Water depth below ground surface (inches).

The monitoring well data shows similar groundwater response down-gradient of the canal in all locations. In all locations, groundwater depths were greater than three feet prior to the commencement of canal flows in May of 2004. Groundwater depth decreased over the first month of operation, indicating seepage from the canal was steadily adding to the local shallow aquifer. In all monitoring well locations, the surface of the water table rose to the ground surface on or before June 15. Well data then shows that the groundwater surface was coincident with the ground surface for the remainder of the monitoring period.

The purpose of obtaining monitoring well data was to provide an indication of reduced seepage by showing reduced groundwater levels down-gradient of the canal. Observations of surface water at the monitoring well sites during the previous irrigation season constituted the baseline data for the polymer application study. Since the monitoring well data shows no change from the baseline condition, it is evident that the seepage flow rate from the canal to down gradient areas was large enough to raise the local groundwater elevation to the ground surface for most of the irrigation season.

Clearly, enough seepage still occurred to saturate down-gradient areas. Since the subsurface characteristics of the vicinity are not known, it is not possible to estimate the

SECTION III - 3
amount of seepage required to result in the appearance of surface water. Clearly, a zero
seepage rate would result in no surface water, whereas the seepage rate required to
maintain surface water could be quite low. Therefore, the monitoring well data shows
that the reduction in seepage did not approach 100 percent. Although the seepage rate
may have been reduced by the polymer application, monitoring well data does not
provide a means for determining the amount of reduction.

C. Turbidity Measurements

Turbidity of surface water throughout the season was very low. This finding is
concurrent with the low turbidities measured at the Green River and inflow from other
canals. This caused adjustment of the study plan as stated in Section I.

During the actual study, turbidity was measured in the canal as follows:

In reach #1: During polymer insertion events, turbidity was measured upstream of the
insertion point in the canal. Initially, turbidity was then measured every 300 feet
downstream of the insertion point. The results of the 300-foot interval testing were
inconclusive as the turbidity drop across this interval was small due to the low initial
baseline turbidity of the influent water. Based on this review, the turbidity measurement
program was adjusted such that the turbidity was measured at longer intervals.

In reaches #2 and #3 turbidity testing was performed on a weekly basis at four evenly
spaced intervals along each reach. An interesting development was noted: the turbidity
INCREASED through the three reaches. The increase can only be explained by regions
of high velocity in the reach where scour introduces suspended solids to the canal

With this finding it was concluded that turbidity reduction could not be utilized as a
measure of polymer effectiveness on the GRSC. Turbidity measurement is likely a very
good measurement technique for higher turbidity canal water. Our experience was that
turbidity measurement with commercially available field kits requires little time or
expertise to perform efficiently and accurately. Further studies should not discard this method as a means of judging the effectiveness of polymer addition.
IV. RESULTS, COSTS AND BENEFITS

A. Reduction of Seepage

Baseline data across the reaches was obtained on August 5, 2002 and on July 1st, 2003. From gauging data and estimated values, the loss per reach and over all three reaches is shown on Figures 3 and 4 on the following pages. As discussed previously, the estimated error of measurement for flow gauging is 5%. As Figure 4 indicates, both of the baseline measurements indicate seepage losses greater than the error margin, with an average loss of 13%. Multiple flow measurements were performed in the summer of 2004. With two exceptions, these measurement events indicated seepage losses of less than 5%. The greatest seepage loss was noted on May 18, 2004, three days after the canal operations were commenced for the season. It is likely that seepage rates would be higher during the startup period as seepage recharged the local area and bank. The other measured seepage of greater than 10% occurred during high flows when greater seepage rates can be expected.

Barring the use of flumes or other costly flow measurement methods, the data from flow gauging events is the most practical method of measuring larger canal flows. Although the following analysis relies on flow gauging data and contains a certain amount of error, we believe the data quality is sufficient to reach qualitative conclusions concerning seepage and effectiveness. It is entirely possible that the seepage reduction calculated from raw numbers overestimates the actual reduction by as a factor of two or three. If this is the case, the cost analysis and qualitative conclusions reached would not be changed. From the raw data, seepage was reduced across the three reaches an average of 9.5 cfs when comparing summer of 2004 with the prior year. Individual reaches were more difficult to quantify, but average values are estimated to be as follows:

| Reach #1, reduction of seepage | 3.7 cfs per 0.85 mile |
| Reach #2, reduction of seepage | 0.3 cfs per 0.88 mile |
| Reach #3, reduction of seepage | 5.5 cfs per 1.45 mile |
| Total | 9.5 cfs |

SECTION IV - 1
## FLOW GAUGING RESULTS

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**Total Loss:**
- Reach 1: 6 CFS
- Reach 2: 7 CFS
- Reach 3: 6 CFS
- Total: 19 CFS
## FLOW GAUGING SEEPAGE LOSS %

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<th>Date</th>
<th>Gauging Sta. 1-1</th>
<th>Gauging Sta# 1-2</th>
<th>Reach 1 Loss</th>
<th>Gauging Sta. 2-1</th>
<th>Gauging Sta. 2-2</th>
<th>Reach 2 Loss</th>
<th>Gauging Sta. 3-1</th>
<th>Gauging Sta. 3-2</th>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2%</td>
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</table>

All loss measurements are calculated as a percentage of the measured flow at the upstream station for that reach. The total column calculates seepage loss as a percentage of flow at Sta. 1-1.
As stated in the prior section, many factors enter into the above estimates. Was the reduction of seepage worth the cost? The following analysis presents costs and benefit/cost analysis for the project.

B. Costs and Benefit/Cost Comparisons

Following is an itemization of project costs:

Reach #1:

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<th>Item</th>
<th>Quantity</th>
<th>Unit Cost</th>
<th>Total Cost</th>
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</thead>
<tbody>
<tr>
<td>Chemical</td>
<td>10#</td>
<td>$4.50 / #</td>
<td>$45.00</td>
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<tr>
<td>Labor</td>
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</table>

@ 4488 LF Cost / LF $ 0.22 / LF

Reach #2:

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<tr>
<th>Item</th>
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<th>Total Cost</th>
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</thead>
<tbody>
<tr>
<td>Chemical</td>
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<td>$3.50 / #</td>
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<tr>
<td>Hydromulch</td>
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<td></td>
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<tr>
<td>Water Truck</td>
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<td></td>
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</tr>
<tr>
<td>Labor</td>
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<td>$40.00 / hr</td>
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<td>$3,404.00</td>
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</tbody>
</table>

@ 4646 LF Cost / LF $ 0.73 / LF

Reach #3:

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<th>Item</th>
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<th>Total Cost</th>
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</thead>
<tbody>
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<td>Cleaning</td>
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<td>Chemical</td>
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<td>Hydromulch</td>
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<td>$2,429.00</td>
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<td>Water Truck</td>
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<td>$1,226.00</td>
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<td>$14,798.00</td>
</tr>
</tbody>
</table>

@ 7,656 LF Cost / LF $ 1.93 / LF
### Combined Costs:

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<thead>
<tr>
<th>Item</th>
<th>Cost</th>
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</thead>
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<tr>
<td>Cleaning</td>
<td>$9,888.00</td>
</tr>
<tr>
<td>Chemical</td>
<td>$1,083.00</td>
</tr>
<tr>
<td>Hydromulch</td>
<td>$4,250.00</td>
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<td>Water Truck</td>
<td>$2,146.00</td>
</tr>
<tr>
<td>Labor</td>
<td>$1,840.00</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>$19,207.00</strong></td>
</tr>
</tbody>
</table>

@16,790 LF Cost / LF $1.14 / LF

A benefit/cost ratio of more than 1 is good and less than 1 is not good. To compare benefit/cost, it is assumed that the benefit of a cfs of irrigation water is the dollar value irrigators are willing to pay for it. At an assessment of $5.00/acre, and an appropriation of one cfs/70 acres, the benefit equals ($5.00 x 70 acres = $350.00/cfs). Therefore the Benefit/Cost ratios are as follows:

**Reach #1:**

\[
\text{Reduction of Seepage x $350/cfs} = 3.7 \text{ cfs x $350.00} = 1.288
\]

Reach #1 Cost $

$1,005.00

**Reach #2:**

\[
\text{Reduction of Seepage x $350/cfs} = 0.3 \text{ cfs x $350.00} = 0.031
\]

Reach #2 Cost $

$3,404.00

**Reach #3:**

\[
\text{Reduction of Seepage x $350/cfs} = 5.5 \text{ cfs x $350.00} = 0.130
\]

Reach #3 Cost $

$14,798.00

**Combined:**

\[
\text{Reduction of Seepage x $350/cfs} = 9.5 \text{ cfs x $350.00} = 0.164
\]

Total Cost $

$19,207.00

SECTION IV - 3
Note: If canal cleaning is considered a maintenance item and not associated directly with seepage reduction, with an expected life of 10 years over which the cost is divided, then Reach #3 cost is $5,898.00 and the benefit/cost is:

\[
\text{Reduction of Seepage} \times \$350/\text{cfs} = 5.5 \text{ cfs} \times \$350.00 = 0.326
\]

Reach #3 Cost $ \quad $5,898.00
V. CONCLUSIONS

A. Effectiveness

Polymer was proven to be successful in reduction of seepage in the GRSC. However, the degree of success was variable depending on many factors. In general:

- Best results were obtained in reach #3 by using surface application in a recently cleaned section of canal. These results were enhanced by a July 1st infusion of chemical into the flow of the canal. Cleaning the canal provides better flow characteristics associated with an increased conveyance and more uniform channel slope. This may have contributed to the reduction in seepage by eliminating reduced conveyance areas and associated increased canal depth and driving head. Because the canal cleaning and polymer application were performed in the same reach, the effects of each in reducing seepage are not separable.

- Medium effectiveness was achieved in reach #1 by using chemical infusion into the flow of the canal. On July 1st, turbidity listing shows an approximate 50% reduction of turbidity following a major dosing.

- Least results were obtained in reach #2 by using surface application of chemical in an uncleaned section of canal. Photo 3, shown on page 5 of section II of this report, illustrates the difficulty of spraying up under the bank vegetation, thus a critical area of seepage is unprotected.

B. Cost Effectiveness

The major unknown in developing cost effectiveness figures presented in section IV is longevity. All numbers are prepared using a one-year life of the treatment. If benefits accumulate over two, three, or more years, the ratios would change dramatically. More study is needed in this area.
C. Other Techniques

Other techniques have been suggested. For example, inducing turbidity in the flow by stirring the canal bottom with a backhoe while injecting polymer into the flow. Budget and time constraints did not allow experiments with this and other techniques. Very low and clean spring runoff from the Green River and Horse Creek hampered the ability to provide better data concerning turbidity control.

D. Soils and Permeability Investigations

A comprehensive soil sampling and permeability investigation should be done for subsequent studies. Comprehensive baseline data would then support selection of method, material and control of the seepage reduction effort. Such investigations require significant time and effort in advance of the seepage control work.

E. Injection of Polymer

Mechanical, not manual, methods of injecting polymer into the canal water should be used. Metering pumps for liquid polymer or “bird feeder” devices to meter in dry polymer would be much preferable to the “drip” method or “dissolving briquettes” method. Even with mechanical means, injecting polymer into a variable flow is labor intensive. Availability of power is another major concern.

F. Measurements

Better, more accurate, methods of flow measurement should be employed. This would result in more quantitative differences of flow and therefore more justifiable results. At flow monitoring points, the gauged section of canal should be cleaned and shaped to facilitate accurate gauging. At flow monitoring points, modern liquid level recording devices should be employed to avoid the mechanical problems endured with the paper chart style recorders.
APPENDIX
APPENDIX A
Testing Protocol

1. After reviewing the testing protocols delineated below, create a test record sheet for each sample noting location, soil type, length and diameter of sample, polymer application type and technique, hydraulic conductivity results (data table and graph).

2. Obtain 2 Bulk and 2 Cylindrical Samples from each of the three reaches. Obtain in-site moisture contents and densities. Cylinders 4" in diameter x 3'-0" aluminum pipe. Obtain 10"± depth material in each cylinder.

3. Clearly label cylinders using the reach (1, 2, or 3) and the sample location, and number (1 or 2). Ex. Reach #1, Lower Site, Sample #2.

4. Initially prepare cylinders by trimming soil from the bottom. Field classify soils according to USCS and record.

5. Obtain filter fabric, affix to bottom of sample to prevent soil loss during testing: Stretch across bottom of sample flush with soils, affix tightly to container with strap ties.

6. Determine sample dimensions (length and cylinder diameter).

7. Saturate fully by filling cylinder with water and allowing water to drain through cylinder, do not start control tests until samples are fully saturated. 

   Note: whenever cylinders are filled with water, fill cylinders very slowly using rubber hose with end placed on surface of soil. Do not create voids and holes in the surface of the sample.

8. Perform control tests for all samples by filling cylinder to apply 2.0' of head and starting timer. Measure head above sample periodically throughout the total time interval required for the water to drain to the level of the surface of sample. Calculate gross hydraulic conductivity of the sample per falling head hydraulic conductivity equation.¹

   a. FOR SAMPLES FROM REACH #2 AND #3 ONLY: Obtain polymer products intended for surface (hyrdromulching) application from both manufacturers. Utilize manufacturers recommendations for concentration
to be used in hydromulcher. Mix to obtain solutions at this concentration. Attempt to get pricing to calculate cost per area of application using each product.

b. Apply CIBA product to one sample at each site, Exacto product to the other. Simulate hydro-mulch application to samples at recommended concentration by spraying (window cleaner sprayer or other?) onto surface of samples.

c. Perform falling head test as in 1 through 8 above.

d. Apply another application of polymer in higher amount per acre (1.5 times initial polymer concentration?) to surface of cylinders.

e. Repeat c above.

f. For samples from REACH #1 ONLY:\ In reach #1 polymer will be infused into the canal water utilizing polymer blocks that will be placed in the canal. Determine the amount of polymer needed in solution form to duplicate the desired concentration in the canal. Mix the solution with a turbid water sample applied to the cylindrical soil samples. Turbid water sample will be formulated by screening bulk samples from reach #1 at the #200 sieve and mixing the fines with the water to be used in the hydraulic conductivity sampling.

g. Perform steps c, d, and e above on the reach 1 sample.

Note: Recognize that the permeability testing conducted in the lab does not simulate canal conditions. In particular, these laboratory tests do not account for the velocity of the water in the canal. Moving water with entrained colloidal sediments may interact differently with both dissolved and surface applied polymer in ways that affect the impact of the polymer on canal bottom hydraulic conductivity.
APPENDIX B
Chemical Suppliers

Ciba Specialty Chemicals Corporation

Contact: John M. Putnam
Littleton, CO 80120
E-Mail: john.putnam@cibasc.com

Product Used: ALCLAR 662 “Proseal PC”

Exacto, Inc.

Address: 7617 State Route 31
Richmond, IL 60071

Phone: 815-678-2206

Contact: Darrell Thorpe
410 South Center Street
Eustis, FL 32726
E-Mail: dthorpe@exactoinc.com
Phone/Cell: 352-357-5606
Fax: 305-675-3300

Product Used: Polytex EC
APPENDIX C
Testing Equipment

Flow Recorders:

• 2 – Stevens Type A liquid level recorder with float in stilling basin. Battery driven with 3 month chart

• 1 – Gurley/Teledyne, Type A, propeller meter. Top setting staff.

• 1 – Turbidity Meter: Hanna Instruments - HI93703
<table>
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<th>Date</th>
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<th>Gauging Sta# 1-2</th>
<th>Reach 1 Loss</th>
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<th>Gauging Sta# 2-2</th>
<th>Reach 2 Loss</th>
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**FLOW GAUGING RESULTS**

(CFS)

NELSON ENGINEERING
Professional Engineers & Land Surveyors
APPENDIX E
Nelson Engineering Staff

Project Manager: Albert L. Nelson, PE/LS
Vice President, Nelson Engineering
P.O. Box 1599
Jackson, WY 83001
Phone: 307-733-2087
Cell: 307-690-2087
E-Mail: boots@nelsonengineering.net

Geotechnical Engineer: Phyl Gyr, PE
Nelson Engineering
P.O. Box 1599
Jackson, WY 83001
Phone: 307-733-2087
Cell: 307-690-8086
E-Mail: pgyr@nelsonengineering.net

Engineering Technician: Tucker Southern
Nelson Engineering
P.O. Box 1599
Jackson, WY 83001
Phone: 307-733-2087
Cell: 307-690-2334
E-Mail: tsouthern@nelsonengineering.net