IRRIGATION RETURN FLOW WATER QUALITY AS AFFECTED BY IRRIGATION WATER MANAGEMENT IN THE GRAND VALLEY OF COLORADO

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IRRIGATION RETURN FLOW WATER QUALITY AS AFFECTED BY IRRIGATION WATER MANAGEMENT IN THE GRAND VALLEY OF COLORADO

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SECTION I

INTRODUCTION

Statement of Problem

In the late spring of 1974, officials of the U. S. Environmental Protection Agency, Region 8, in Denver, Colorado contacted researchers of USDA Agricultural Research Service, Fort Collins, Colorado regarding the possibility of an interagency research program relative to the quality of return flows from irrigation in the Upper Colorado River Basin. At that time, the EPA foresaw upcoming regulations concerning the regulation of return flow from irrigation and expressed considerable interest in evaluation of the relation between irrigation practice and quality of return flows. Of specific interest were identification of the variables needed to effectively detect and manage irrigation return flows and evaluation of the best practical irrigation technology applicable to the area.

Ongoing ARS Research in the Grand Valley

In March 1973, the Agricultural Research Service entered into an agreement for partial research funding by the Bureau of Reclamation, U. S. Department of Interior to evaluate salt in return flows and develop irrigation techniques to reduce salt loading. One of the primary objectives of this study is to provide a field test of a low leaching concept conceived by personnel of ARS's U. S. Salinity Laboratory, Riverside, California, whereby frequent light irrigations are applied so as to maintain adequate water for crops and at the same time reduce the leaching fraction sufficiently to induce precipitation of salts concentrated by plant water use.

This effort required establishment of a work location in Grand Junction and assembly of a permanent staff. The current location staff consists of a soil chemist, an agricultural engineer, three technicians, a secretary, and seasonal help as required. With the help of U. S. Salinity Laboratory personnel, the Grand Junction and Fort Collins staff installed a center pivot irrigation system, covering 26.5 acres, with instrumentation to measure water application, percolation, evapotranspiration and soil salinity changes under each of two replications of three water treatments. Similar instrumentation was provided for four furrow irrigation plots.

Subsequently, the study was expanded to include seepage measurements in the main canals and in the open drains, geologic and groundwater characterization in the vicinity of the intensive studies, and analysis of wintertime flow and chemical concentration in the washes. These latter studies were designed primarily to attempt to identify the mechanism by which return flows reach the river.

Copies of annual progress reports are available to cooperating agencies.

Objectives of Current Study

The current study was designed to meet the specific needs of the Environmental Protection Agency consistent with the interests and research goals of ARS. The research is complementary to other ongoing ARS studies in the Grand Valley and some phases are an extension to a wider range of soils and management practices of studies begun under the USBR project. The specific objectives of the current study are:

1. To identify the variables needed to predict the effects of deep percolation, tailwater runoff, and lateral seepage on the quality of return flows. Includes evaluation of both quantity and quality of the various components of the field water balance.
2. To define the effect of irrigation water management on the quality of runoff and deep percolation leaving the farm unit and determine the reduction in both water and salt losses that can be achieved by improved irrigation technology.
3. To identify the mechanisms by which the salt load of return flow water is modified after it leaves the farm unit and moves toward the Colorado River and attempt to determine the most practicable methods of controlling further salt accretion between the farm unit and the river.
4. To evaluate the experimental methods used in the above studies with regard to their applicability in other similar irrigated river valleys.

SECTION II

SUMMARY OF RESULTS

As discussed elsewhere in this paper, the results of some phases of the study varied widely throughout the valley. Only total and/or mean values are reported in this section. For more detailed analyses, including statistical interpretations of the variations measured, the reader is referred to the appropriate section in the text of the report. The location of supporting discussion is indicated by page numbers in parentheses.

It is concluded that a major source of subsurface return flow is seepage from the unlined delivery system, although it may enter the river through the natural drains (70). The canals and lateral ditches combined are estimated to recharge about 100,000 acre feet of water annually (70). If all this water passed through the cobble aquifer, which it does not, and returned to the river at the salinity of the aquifer water, it would account for virtually all the salt load of the Colorado River attributed to the Grand Valley. A portion of this water, however, returns to the washes at a lower salinity level than occurs in the aquifer. The winter base flow, which includes water from all seepage sources, in nine washes monitored is estimated to return salt at a rate of 104,000 tons per year (76). Extrapolating these data to all drains in the valley and considering that high groundwater levels undoubtedly result in larger groundwater flow into the washes during the summer, results in an estimated total open drain contribution at least twice the value reported. In any case, it appears that the direction and salt concentration of seepage return flow are dictated by geologic conditions, and are practically independent of the rate of seepage (70).

Infiltration rates of irrigated soils were found to be quite variable, with respect to both time and location. Cumulative 12 hour infiltration ranged from 3.4 to 13 inches during the first irrigation of the season, and approximately half that value (1.6 to 6.9 inches) during subsequent irrigations (41). Since current practice dictates extended irrigation periods during the first irrigation to wet the seedbed, it is probable that a large fraction of the leaching occurs at that time.

Deep percolation losses range from virtually none in parts of the western end of the valley to quite high values east of Grand Junction. For the valley as a whole, the estimated leaching fraction was not large, averaging about 0.13 (55). Thus, the total volume of percolate is about 28,000 acre feet per year, or 22% of the total estimated seepage (55). As was the case with canal seepage, the ultimate quality of percolating water is not proportional to the volume.

Of the total irrigation water applied to the fields, tailwater runoff averaged 33.6 percent (41). These large amounts of runoff are necessitated by the generally low infiltration rates and the necessity of "wetting across" to obtain seed germination. This runoff water carries an average of 2.2 tons sediment per acre foot of runoff water, resulting in an average erosion rate of 0.02 inches annually. The sediment and a small amount of phosphorous were the only detectable evidence of deterioration of water quality in the runoff (65). Pesticide concentrations were not taken into consideration.

Crop evapotranspiration from corn during the growing season was measured at about 32 inches under furrow irrigation and 27 inches under sprinkler irrigation (60). One very significant conclusion is that airborne evaporation from the sprinkler nearly equals the reduction in ET under the sprinkler. Since a portion of the net solar energy is used to evaporate airborne water directly, a correspondingly smaller amount of energy is available for transpiration. Thus, direct evaporation cannot be construed as wasted water application. During the period of full crop cover, measured ET was about 30 percent greater than estimated by the ARS scheduling program (60). This has led to intensive efforts at recalibration of the coefficients used in the computer program to represent conditions in the Grand Valley.

SECTION III

CONCLUSIONS

Variables Needed to Predict Effects of Irrigation on Quality of Return Flows

For purposes of this report, return flows may be logically divided into two distinct components. The first remains as surface water throughout its course from diversion from the river to its return to the river via the natural washes and constructed surface drains. During the irrigation season, a varying but substantial portion of diverted water is deliberately spilled from canals into these drains for control of canal delivery. In all cases studied, the natural drains were observed to increase in discharge with distance downstream from the Government Highline Canal (i.e., the upper limit of the irrigated area), even during the winter when groundwater levels are lowest (76). This indicates that water table elevations are higher than surface water levels in the drains and that deliberately spilled water does not enter the aquifer in significant amounts. Thus the spillage per se would not be expected to result in significant salt loading of the river.

Tailwater runoff from irrigation was not found to dissolve a statistically significant amount of salts from the soil for transport to the river (65). This tailwater runoff, however, does remove significant amounts of sediment and small, but detectable amounts of phosphorous associated with this sediment (65). Thus, from the standpoint of salt contribution, the surface water component appears to be a minor contributor to degradation of return flow, except for the deep seepage that may occur from tailwater ditches and shallow drains.

The second component of return flow is that water which percolates through soil material prior to entering the river, either as direct underflow or via the surface drains. Although the path of this water, and the geologic materials it contacts, varies considerably, it appears to equilibrate with the soluble gypsum and calcite present. As percolation rates are reduced and transit time of groundwater increases, other soluble salts will undoubtedly increase in concentration somewhat. However, since the groundwaters are, for the most part, saturated with gypsum and calcite, the net long term result of reduced seepage will be a reduction in total salt load.

Control of salt loading is dependent almost solely on control of the water itself. As mentioned in the previous section, canal and lateral seepage appear to be the major source of this subsurface component of return flow (70). Deep percolation is affected by the variable infiltration rate of the soil, by poor provision for water measurement, and by the long infiltration opportunity time needed to apply required amounts of water.

Reduction in Water and Salt Losses Achievable by Improved Irrigation Technology

Although not technically water losses, the surface return flows from irrigation can be eliminated by application of available technology. Conversion to a strict demand diversion would eliminate the necessity for canal regulation by spillage. Tailwater recovery systems, advanced automation devices, or possibly an adaptation of the dead level irrigation concepts used in parts of the Southwest would allow elimination of tailwater runoff and its associated sediment.

It appears from our studies that an impervious water delivery system would provide the most significant reduction in both quantity and quality of return flow. Estimated canal and lateral seepage could, if returned to the river at the salinity of the aquifer, carry much more salt than the total estimated salt loading through the Grand Valley. Even at the average measured base flow salinity of EC 4.4 mmhos/cm (much lower than the salinity of the cobble aquifer), the combined canal and lateral seepage of 100,000 acre feet annually would return in excess of half a million tons of salt (70).

Although we must conclude from our studies that deep percolation is not the major source of return flow (55), there is room for improvement, particularly on some soil types. Perhaps modified tillage practices to leave crop residue near the surface or modified planting practices to reduce the need for long irrigations, particularly early in the season when infiltration rates are high, would prove viable improvements. As applied in the Southwest, dead level irrigation allows very uniform distribution of small applications of water, such as needed for germination. These concepts are as yet unproven for the Grand Valley, but are the subject of ARS research being initiated at this time.

However, regardless of the degree of control attainable over water application, some leaching must occur to attain a favorable salt balance in the soil. Although we have sustained production under very low leaching fractions under the sprinkler in the Bureau of Reclamation study, it is doubtful whether adequate salt control can be attained under surface irrigation with leaching fractions less than 0.1 because of natural variability of soils within a field. At this rate, leachate return flows would exceed 15,000 acre feet per year, with an accompanying salt load of from 80,000 (at EC of washes) to 200,000 (at EC of saline aquifer) tons per year.

Mechanisms of Modification of Return Flow Water

Surface water return flows apparently suffer little degradation in passing from the canals back to the river via the natural washes. Tailwater runoff from irrigated fields carries substantial amounts of sediment, but the only ionic constituent showing a detectable increase in concentration is phosphorous (65). Though this surface return flow does not technically constitute a loss of water from the system, large acreages surrounding the washes lie waste and support only weeds and phreatophytic plants. These plants undoubtedly consume a significant amount of water for nonproductive plant growth. The tortuous path of the washes and the extreme depth (30 feet or more in many places) necessary to transport spillage and occasional storm runoff from the desert above result in removal of much otherwise irrigable land from production.

Both deep percolation from irrigated land and seepage from the delivery system, which is apparently the most significant source of return flow (70), enter the groundwater system. Where the shale is intersected by ditches or overlain by shallow soils, percolating water enters directly into a bedded, jointed, quite permeable shale zone capped with impervious clay derived from the surface of the shale (76). Within this zone, water moves in very unpredictable paths, and may return after a short time directly to the washes. It may also move downslope to emerge in lowerlying canals, or to rise through discontinuities in the clay cap into the cobble aquifer or the shallow overlying soils. Deep percolating water may be intercepted by discontinuous clay lenses resulting in lateral flow or percolate to the Mancos shale over which it flows downslope to drain into the washes or enter the very saline cobble aquifer. Regardless of the path of subsurface return flow, abundant soluble salts are present in the geologic strata. We conclude that the salt concentration in the subsurface return flows will be increased less by each successive increment of reduction in seepage, so that reduction of seepage (percolation) volume will result in reduction of total salt mass returned to the river.

SECTION IV

RECOMMENDATIONS

At the outset, it must be emphasized that the following recommendations are based solely on the physical benefits to be derived. The scientists involved in this research are well aware that economic, social and legal restraints will influence the degree to which these recommendations can be implemented, at least within the immediate future.

The one change that would allow most effective improvement of irrigation in the Grand Valley would be implementation of a demand delivery system. Such a system, requiring individual water orders be placed at least as far in advance of need as the canal transit time, would eliminate the need for canal spillage, and eliminate much of the lateral and farm ditch seepage resulting from continuous delivery. The present surface water law gives little incentive to efficient water management, and in fact penalizes the water right holder who attempts to improve efficiency, as he apparently cannot receive restitution for that portion of his right not diverted. During peak use periods, the entire capacity of most canals is needed to satisfy ET, yet the remainder of the season much diverted water is not needed and returns to the river. A demand system would allow on-farm delivery, on a rotational basis, of sufficiently large flow rates to effectively utilize automated irrigation systems and other advanced management techniques.

If one accepts our conclusion that the primary source of groundwater contribution is seepage from the delivery system, it follows that the greatest improvement in return flow water quality would be realized from an impervious delivery system. To most effectively integrate a demand delivery system and provide for implementation of improved on-farm water management, we recommend a system based on lined open canals for the primary distribution system with closed conduit lateral delivery from the canals. Such a system would provide precise control of distribution from the lateral and provide low pressure heads necessary for operation of underground and/or gated pipe distribution on the farm. Such a system has many benefits to the irrigator as well as the water supplier. Besides reducing seepage losses, it eliminates weed growth and associated maintenance costs and recovers otherwise productive land for crop production. Elimination of field ditches, for example, recovers not only the area occupied by the ditch, but also the turn row needed below the ditch, an estimated 3 acres per mile of ditch. Such a system can also follow a more direct route from canal to farm, eliminating many small areas presently uneconomical to farm.

Computer scheduling of irrigation has been proven in many areas, and is certainly adaptable to the Grand Valley. Obstacles to its immediate success in the valley are lack of water delivery on demand

and lack of reliable methods of water measurements. Any system improvement must include provision for readily determining amount of water delivery, and, if permitted, of tailwater runoff. An extension of the scheduling concept is the subject of current ARS research at Fort Collins. This extended concept integrates irrigation scheduling with systems analysis to give optimum allocation of water to those delivery points at which it is most urgently needed. Such an approach, with the prediction presently built into the scheduling program, would provide not only a farm management tool but also an invaluable canal management tool. Implementation of such an approach, however, will obviously require a change in both social and legal attitudes.

Numerous cultural practices proven successful in other irrigated areas hold promise for improving irrigation in the Grand Valley. Several areas in the desert Southwest utilize large flow rates into level basins to obtain very uniform water application with no tailwater runoff. With large flow rates, a predetermined volume of water can be applied in a short time and allowed to infiltrate after inflow has ceased. Thus application depth can be precisely controlled. Minimum tillage or no-till practices adopted in many areas may prove feasible to increase infiltration, control crusting and reduce sediment load. Modified planting practice to place the seedbed nearer to the water furrow would, if successful, greatly minimize the need for long irrigation times to obtain germination in the spring when infiltration rates are high. Each of these practices is yet to be proven before recommendation in the Grand Valley, and is a current subject of ARS research in the area.

SECTION V

DESCRIPTION OF METHODS USED

Components of Water Balance

Before one can determine the effects of various hydrologic components of irrigation on the ultimate quality of return flows to the river, the magnitude, thus the relative importance, of each of these components must be determined. Traditional methods of on-farm water balance determinations involve direct measurement of surface water movement in the liquid phase, estimates of vapor flux (primarily evapotranspiration from cropped areas) and assuming the remainder is lost to percolation. As a result, all measurement errors associated with irrigation application are lumped into the percolation component. These errors can well be several times greater than the percolation itself. For this reason, attempts were made to determine each component of the water balance individually for the current study. Description of the techniques used to quantify the various hydrologic components follows.

Delivery Losses. Water delivery losses in the Grand Valley irrigation system are rather unique because of the continuous flow method of operation. River diversions may vary with season, but do not vary with day-to-day irrigation demand. As a result of irregular irrigation demand, excess canal flows are spilled directly into the drainageways (either natural or man made) through which the water returns to the river. Although these drains do receive saline water from the groundwater, seepage measurements made as a part of the USBR study indicate that little water enters the aquifer from the drains. Thus, this spillage water itself contributes insignificantly to salt loading of the river. For this reason, measurements of this spillage were not attempted as a part of this study.

Evaluation of delivery losses was confined to measurements of seepage from the main delivery canals and laterals serving the farmer. Because the canals flow continuously during the irrigation season, tests were necessarily confined to pre- and post-irrigation season. Tests were conducted on one lateral using flumes for inflow-outflow measurements over a reach of canal. Such measurements were impractical in most cases because the expected error of flumes approaches or exceeds the expected seepage rate over reasonable lengths of canal. The majority of seepage tests were conducted by constructing temporary dams across both ends of a canal reach, filling the resulting pond with water, observing the rate of water surface decline, and correcting for evaporation loss. Fall ponding tests were conducted immediately after canals were shut down, using remaining canal water to fill the ponds. Spring tests were conducted on short reaches, as river water had to be hauled by truck to fill the ponds prior to first canal diversions.

Applied Irrigation Water. Studies to determine efficiency of furrow irrigation application were conducted on a total of 27 fields throughout the Valley, representing eight major soil types. To allow accurate determination of advance times and assure uniform furrow flows, applied irrigation water was measured with a special orifice box serving either two or four furrows. This box was installed and leveled immediately adjacent to the field ditch so that the farmer could set his siphon tubes into the orifice box to irrigate the test plots just as the remainder of the field. The orifice boxes were fitted with water stage recorders to allow determination of time, rate and volume of irrigation application. Two fields were equipped with flumes for inflow measurements, as the ditch location was unsatisfactory for the orifice box. Individual furrow flumes were used at one site, a trapezoidal flume in the delivery ditch at the other site.

Because infiltration rates are generally quite low in the Valley, the typical farmer irrigation practice is to apply water at such a rate that it reaches the end of the furrow in four to six hours, then continue irrigation for a total of 24 to 48 hours. As a result, considerable amounts of irrigation water leave the field as tailwater runoff. This tailwater is subsequently reapplied to lower fields, or returns to the river via the surface drains. All study sites were equipped with flumes having water stage recorders to measure tailwater runoff from the area of inflow measurements. These data allowed determination of inflow, outflow, and application, and in most instances rate of advance, from which intake rates could be estimated.

Soil Water Measurements. A further component of the water balance picture is the amount of irrigation water stored in the soil for subsequent plant use. Soil water storage by irrigation was estimated by periodic determination of water content in the root zone. Eight sites were instrumented with three access tubes each for neutron moisture measurement. Water content was measured in each field before and after each irrigation. Interference with the cropping procedures, shallow soils, and limited personnel prohibited neutron measurements in all fields under study. Soil water content was determined periodically by gravimetric methods to supplement neutron data, to check neutron calibration, and to provide samples for soil chemical analysis.

Deep Percolation Losses. The most difficult parameter of the water balance to measure directly is the percolation of water beneath the root zone. Deep percolation is a very important component of the water balance, since it is this water, along with seepage from canals, that has the best opportunity to dissolve salts from underlying formations and subsequently return these salts to the river. Because it is so difficult to measure directly, deep percolation is most often calculated by measuring or estimating the other components of the field water balance, then solving the continuity equation for the deep percolation. This procedure has the effect of lumping all measurement errors into the value of the deep percolation. Since this parameter is usually (or at least desirably) a small fraction of the applied irrigation water or evapotranspiration requirement, the percentage error of deep percolation estimates by this technique is frequently large. Numerous techniques for independent estimates of deep percolation were evaluated as a part of this study.

Vacuum Extractors. A direct measurement device developed by Duke and Haise (1973) was installed at five of the sites at which irrigation application efficiencies were studied. This device, called a vacuum extractor, consists of a pair of porous ceramic tubes placed in the bottom of a soil filled, open topped metal trough. This trough, with a rubber air bag attached to the bottom, is installed in a rectangular shaped, horizontal tunnel formed in undisturbed soil beneath the crop root zone as shown in Figure 1. After the trough was placed in the tunnel, the air bag was inflated to press the open top of the trough against the undisturbed soil above to maintain hydraulic contact. Vacuum applied continuously to the candles intercepts percolating water, presumably at the rate of natural percolation, and collects this percolate in a bottle for subsequent measurement and chemical analysis.

The developers (1973) reported that percolation rates could be measured within 15 percent in laboratory tests. The accuracy of the device depends upon control of the applied vacuum such that the soil water suction at the top of the trough is precisely equal to that in the ambient soil at the same depth outside the trough. Such control is most readily achieved with coarse textured soils in which hydraulic conductivity decreases rapidly with increasing soil water suction. Such soils are not encountered at the study sites in the Grand Valley. In these fine textured soils, the leachate measured by the extractor is quite sensitive to applied vacuum. Because of the high hydraulic conductivity at relatively low soil water suction, the extractors are also readily influenced by a water table near the extractor trough. For this reason, many of the sites investigated by the chloride profile technique were considered unsuitable for vacuum extractor installation. Results from some of those extractors installed are suspect because of unexpectedly high water tables resulting from nearby ditch seepage.

Nonweighing Lysimeters. As a part of the USBR studies, ARS installed six nonweighing lysimeters under a center-pivot sprinkler irrigation system. These lysimeters are fabricated of fiberglass panels with ceramic tubes in the bottom to allow percolating water to be drawn off. The boxes are 1.5m square, 45cm deep, with the bottom of the box at 90cm below the soil surface. Thus, assuming water is removed to prevent buildup of a water tables and subsequent leakage, these lysimeters should, when corrected for changes in water storage, give an accurate estimate of deep percolation, However, the fact that the nonweighing lysimeters were installed by excavation and refilled with disturbed soil limits their usefulness for

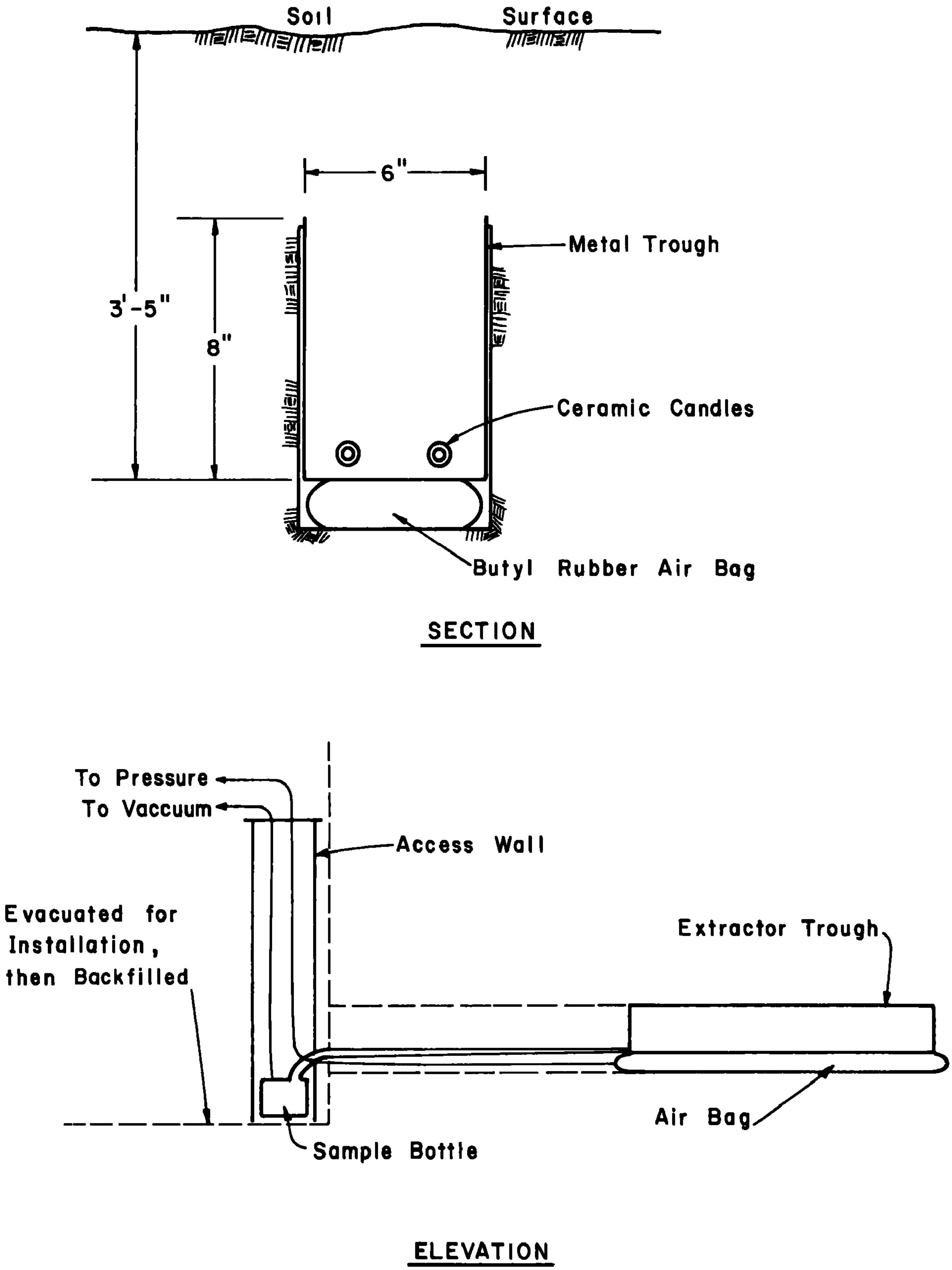

Figure 1. Schematic of vacuum extractor installation

collecting samples for chemical analysis. Because excavation and replacement of a soil may change its infiltration rate by several orders or magnitude, these devices should not be used under gravity irrigation where infiltration rate controls the water intake. Under the sprinkler system, infiltration is controlled by the sprinkler at a rate sufficiently low to prevent runoff.

Soil Chloride Profiles. The above described techniques require a considerable amount of equipment and time for installation and operation, thus are not particularly suited for large scale surveys of current irrigation practice. A technique of estimating deep percolation based on salt concentration below the root zone has been used with apparent success in other areas, and was suggested for evaluation as a survey technique by chemists at the U. S. Salinity Laboratory, Riverside, California. The primary reason that irrigated agriculture inevitably results in concentration of salt is that the plants extract soil water while selectively excluding from plant uptake practically all ions in the soil solution. As the soil solution moves progressively deeper in the soil root zone, more water is extracted and the salt concentration in the remaining water increases. Because of the complex chemical reactions, this increasing concentration may result in exchange of adsorbed cations, precipitation of some salts and dissolution of others. Thus, most ion species are in a rather dynamic environment. However, the chloride ion is relatively unaffected by these reactions. Being an anion, it is not adsorbed on the clay complex. Common Cl^- salts are quite soluble in water, thus are not present in solid form in irrigated soils. Thus, the concentration of Cl^- in the soil solution is a direct function of the Cl^- concentration in the irrigation water and the fraction of that water removed from the soil by evapotranspiration (ET). Thus, if the Cl^- concentration of the soil solution is evaluated at a depth below which no further ET occurs, the ratio of Cl^- in the irrigation water to Cl^- in the soil solution is the fraction of applied irrigation water leaving the root zone as deep percolation (leaching fraction). Further, if percolation can be construed to be sufficiently slow that short term changes in water quality or leaching are damped at the depth of sampling, the chloride concentration at that depth can be construed to represent the long term average result of historic irrigation practice and, a one-time sampling program can be used to characterize the leaching history of an area.

To evaluate this technique, numerous soil samples were collected from each of 28 fields representing the major soil types in the Grand Valley.

Evapotranspiration. The second parameter of the water balance not readily measurable is the evapotranspiration. Numerous techniques have been developed to estimate ET, ranging from strictly empirical approaches to correlation with pan evaporation and sophisticated energy balance approaches. The technique used in this study is a modification of the ARS Scheduling Program as presented by Jensen (1969) and Kincaid and Heermann (1974). This program uses a modified energy balance technique in which solar radiation, average temperature, dew point temperature and daily wind run are used to estimate the net energy available for evapotranspiration. Portions of this program related to estimation of net solar radiation, soil heat flux, and vapor transport are empirically derived, and it was desirable to check these calibration equations for the Grand Valley area. The energy balance portion of the model calculates the potential evapotranspiration, that is the ET from a well watered crop having a full cover. Therefore, a lysimeter was installed in an established alfalfa field to check the potential ET calculations. This lysimeter was filled with a monolith of established alfalfa to avoid excessive delay in establishment of a permanent stand in the lysimeter.

Following calculation of potential ET, the ARS Scheduling Program applies a stage of growth curve for each crop type to calculate actual ET. The lysimeter previously installed for the USBR study was under the sprinkler system where the corn is irrigated as often as four times daily. Thus it was desired to check the crop coefficients under more conventional irrigation practice. Three additional lysimeters were installed in furrow irrigated fields planted to both corn and sugar beets.

The four lysimeters installed were of the hydraulic type described by Hanks and Shawcroft (1965). The principle of operation is illustrated in Figure 2. The inner box, in which the plants are grown, rests on two pillows fabricated from reinforced butyl rubber pipe. These pillows, filled with ethylene glycol solution, transmit the fluid pressure resulting from the weight of the lysimeter to a manometer where pressure changes can be read as a function of time. To minimize problems of temperature effects on fluid density and to reduce manometer height necessary, a portion of the pressure, representing the bulk of the lysimeter weight, was tared by inserting a mercury column in the manometer line. This taring device is so designed that the readout manometer can be installed in a pit below the soil surface, yet retain the sensitivity of a water manometer. The sensitivity of the system is approximately 5mm manometer change for each mm change in soil water.

Water Analyses

In conjunction with measurements of the various components of the water balance, periodic samples of each of these components were collected for laboratory analyses of water quality.

Sediment Concentration. Since rather large volumes of tailwater runoff characterize current irrigation practice in the Grand Valley, it was suspected that sediment concentration would serve as a direct indicator of the presence of runoff in return flows. Therefore, sediment concentrations were determined gravimetrically for both applied irrigation water and tailwater runoff. A total

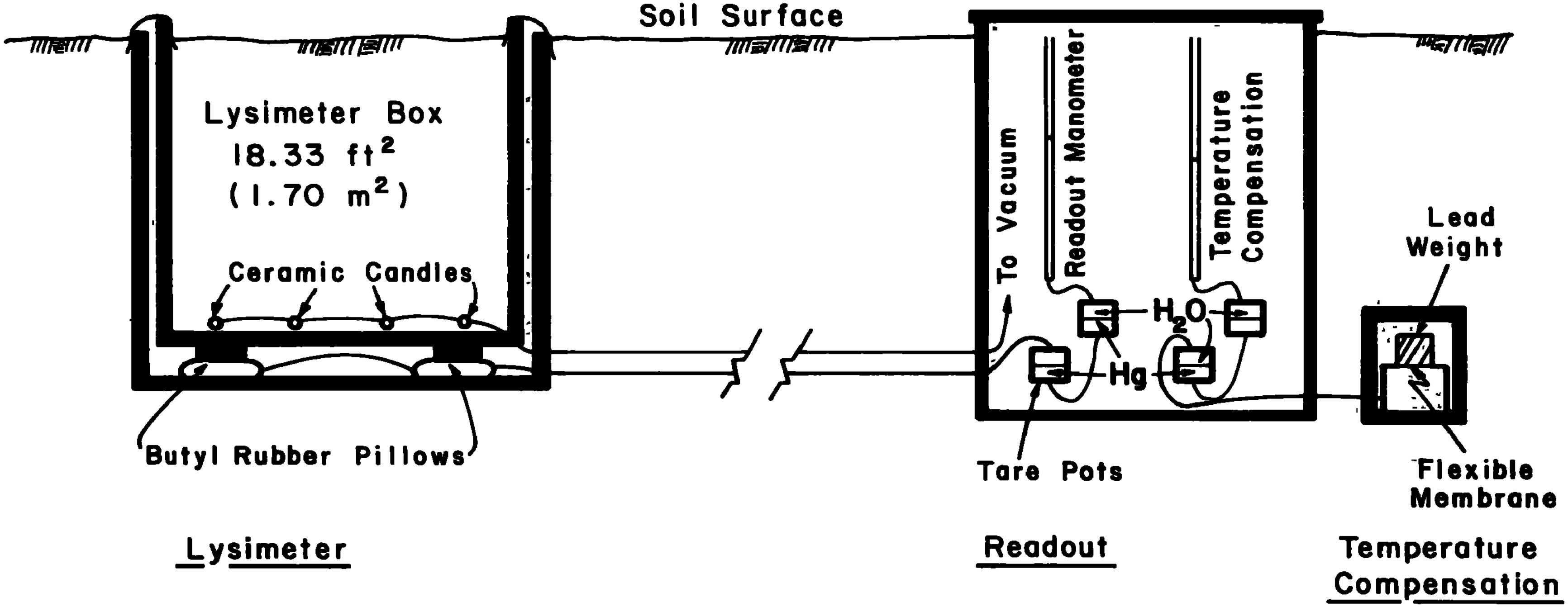

Figure 2. Operational diagram of hydraulic lysimeter

of 81 samples of irrigation and runoff water were collected for sediment analysis, in addition to periodic samples from the Government Highline Canal and the Colorado River at Grand Junction.

Chemical Analyses. Literally thousands of individual chemical analyses have been run on soil and water samples collected during the course of this study. The analyses were conducted in ARS laboratories at Grand Junction and Fort Collins, with those collected in conjunction with USBR studies conducted by the U. S. Salinity Laboratory in Riverside, California. Specific analyses conducted on the various samples are given in Table 1.

Table 1. Chemical analyses conducted on various samples.

						Ion				
Sample	EC	Ca	Mg	Na	K	P	HCO_3	Cl	SO_4	NO_3
Soils for chloride study								X		
Drain flow	X	X	X	X			X	X	X	X
Applied irrigation water	X	X	X	X	X	X	X	X	X	X
Tailwater runoff	X					X		X		X
Percolate samples (extractors)	X	X	X	X	X		X	X	X	X
Groundwater (observation wells)	X	X	X	X	X		X	X	X	X

SECTION VI

DESCRIPTION OF FIELD SITES

The Grand Valley of Colorado comprises some 56,000 acres of irrigated land (SCS 1976 survey) along the Colorado River both directions from the confluence of the Gunnison and Colorado Rivers. Irrigation apparently began about 1883. Early studies (Miller, 1916) indicate that both ground water and soil salinization had become problems by about 1915. Ground water quality has apparently deteriorated little since that time, but increased demands on the water of the Colorado River have made the problem of saline return flows increasingly important.

The irrigated areas of the Grand Valley overlie the Mancos shale formation, from which most of the soils were derived. This shale, of marine origin, is interspersed with lenses of crystalline salts, which are readily dissolved when water contacts these lenses. As the river migrated back and forth across the valley, it eroded the underlying shale and subsequently filled the resulting channel with cobble. The resulting aquifer has long been too saline for agricultural or domestic use. Likewise, intermittent streams from the desert and Book Cliffs to the north cut channels perpendicular to the river. As a result, topography of the shale surface is very complex, with shale outcropping frequently, especially in the northern and western portions of the irrigated area. The intermittent streams from the desert presently cross the irrigated area through ravines, often 30 or more feet in depth. These ravines, along with several man-made ditches, serve as drains, returning groundwater, tailwater runoff, and canal spillage to the river.

The soils resulting from this complex geologic history are quite variable. The 1955 soil survey (Knobel, et. al., 1955) for the valley lists 73 soil series identified in the valley. Although fields are generally small, the field representing a single soil series is the exception. This fact, more than any other, limited the selection of sites for this study. Table 2 lists the proportionate extent of the major soil series of the valley, which comprise

Table 2. Approximate acreage and proportionate extent of major soil series in the Grand Valley

Series	Acres	Percent of Total
Billings	36000	29.5
Ravola	18900	15.6
Chipeta-Persayo	18800	15.3
Fruita	13500	11.1
Mesa (Mack)	8400	6.5
Hinman	3100	2.5

approximately 80 percent of the irrigated area. The studies reported in this paper have involved farmer cooperation at 28 different locations. Table 3 lists the site designation used in subsequent discussion, along with the location and soil series.

Intensive Study

As mentioned earlier, initial ARS studies related to the current problem were begun in 1973 with the cooperation of the Bureau of Reclamation. A primary purpose of that study was to test recently developed theories of minimum leaching. To attain this goal, it was necessary to select a site having minimum potential for a high water table. With the assistance of local Soil Conservation Service personnel, the Ravola series was selected as best representative of well drained soils in the valley. Final selection of the site at 20 1/2 and N Roads was based on relative uniformity of the soil, uniform soil slope, and the interest of the cooperating farmer.

Soil samples were collected immediately upon selection of the site, and a modified center-pivot sprinkler was subsequently installed on a portion of the field. The sprinkler controls were rebuilt to provide water treatments to six sectors of the circle, two replicates of each of three water treatments. It was intended to apply 0, 5, and 15 percent leaching fraction to these plots. Vacuum extractors, non-weighing lysimeters, soil salinity sensors, and recording rain gauges were installed in each of the sectors. A large weighing lysimeter was installed in one plot.

The remainder of the field has been operated under gravity irrigation, with vacuum extractors and salinity sensors used to monitor the results. Water measuring devices were installed to measure both inflow and outflow from each of the four test plots. The experimental layout is illustrated in Figure 3.

The intensive study site lies some 300 m down slope from the Government Highline Canal, and drains into Little Salt Wash, which runs immediately to the southeast. The area has been cropped exclusively to corn since the study began. Virtually every on-farm measurement (i.e., excluding canal seepage and drain flow studies) conducted at other ARS sites in the valley has also been made at this intensive study site.

Soil Chloride Profiles

Because the soil chloride profile technique promised a rapid survey to estimate historic leaching fraction, the technique was used to help locate suitable sites for other desired instrumentation. Samples for chloride analyses were collected at 28 different locations throughout the valley, as illustrated in Figure 4. Sampled fields represented each of the major soil series, and attempts were made to sample fields both where drainage was expected to be good

Table 3. Site Locations

Designation	Name	Address	Soil
BR	Bray	14.5 & 0.5	Billings sltcl & Ravola vfsl
CHR	Christian	2936 B 1/2 Rd	Hinman cl
CSUB	CSU Beets	19 & L	Ravola
CSUC	CSU Corn	19 & L	Ravola
CSUW	CSU West	19 & L	Chipeta-Persayo
DP	D. Phillips	594-31.5	Ravola
EB	Ed Bernal	16 & Q	Ravola loam
EMA	E. Mabie	2146 M	Ravola
EMU	E. Muth	12 & 0.5	Fruita cl
FKW	Furakawa	2968 B Rd	Hinman cl
FOR	Forster	19 & H.5	Billings sltc
G 22-25	E. L. Barbee	20 1/2 & N	Ravola loam
GIE	Gieske	14 & L.6	Fruita cl
HTM	Hartman	10 & Q	Mack (Mesa) clay
IN	Indergaard	16 & P	Billings sltcl
JB	Jim Bernal	16 & Q	Ravola loam
JS1	J. Studebaker	2198 I	Billings
JS2	J. Studebaker	25 & G	Ravola vfsl
KB	K. Buniger	14.5 & P	Billings cl
LDS	LDS Church Farm	20 & M	Ravola vfsl
LF	L. Foraker	643-31	Ravola
LS	L. Sommerville	21 & K Rd	Billings sltcl
PK	P. Kelleher	437-32	Billings
RL1	R. Larson	204-31.3	Mesa clay
RL2	R. Larson	2931-B.5	Hinman cl
RTG	Rettig	31.8 & C	Mesa cl
S 1-6	E. L. Barbee	20 1/2 & N	Ravola loam
SM	Smith	1249-21 Rd	Ravola vfsl
SN	Snodgrass	14.5 & Q	Ravola vfsl
STS	States	11.8 & P	Fruita cl

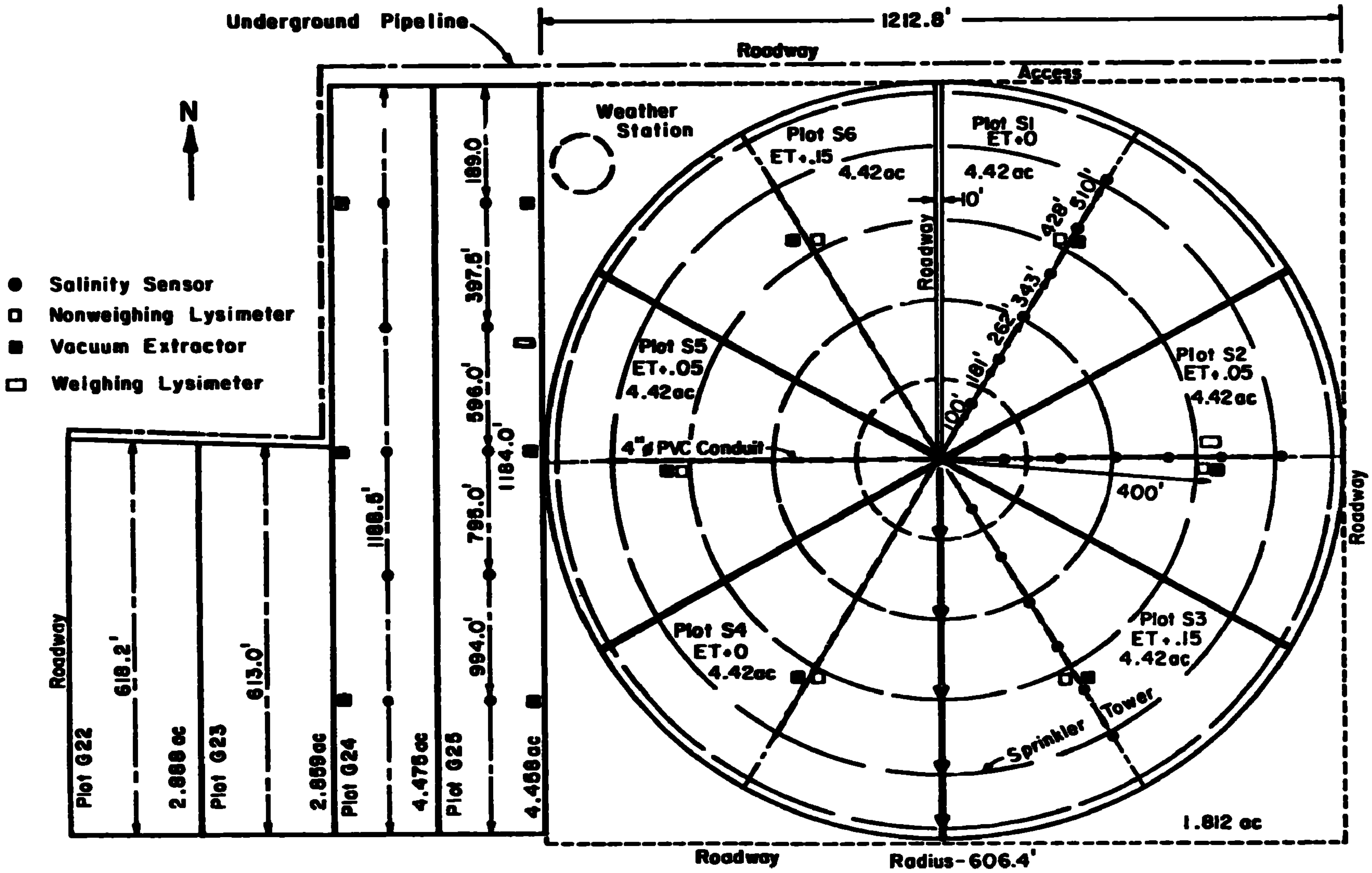

Figure 3. Sketch of experimental field plots and instrumentation at intensive study site

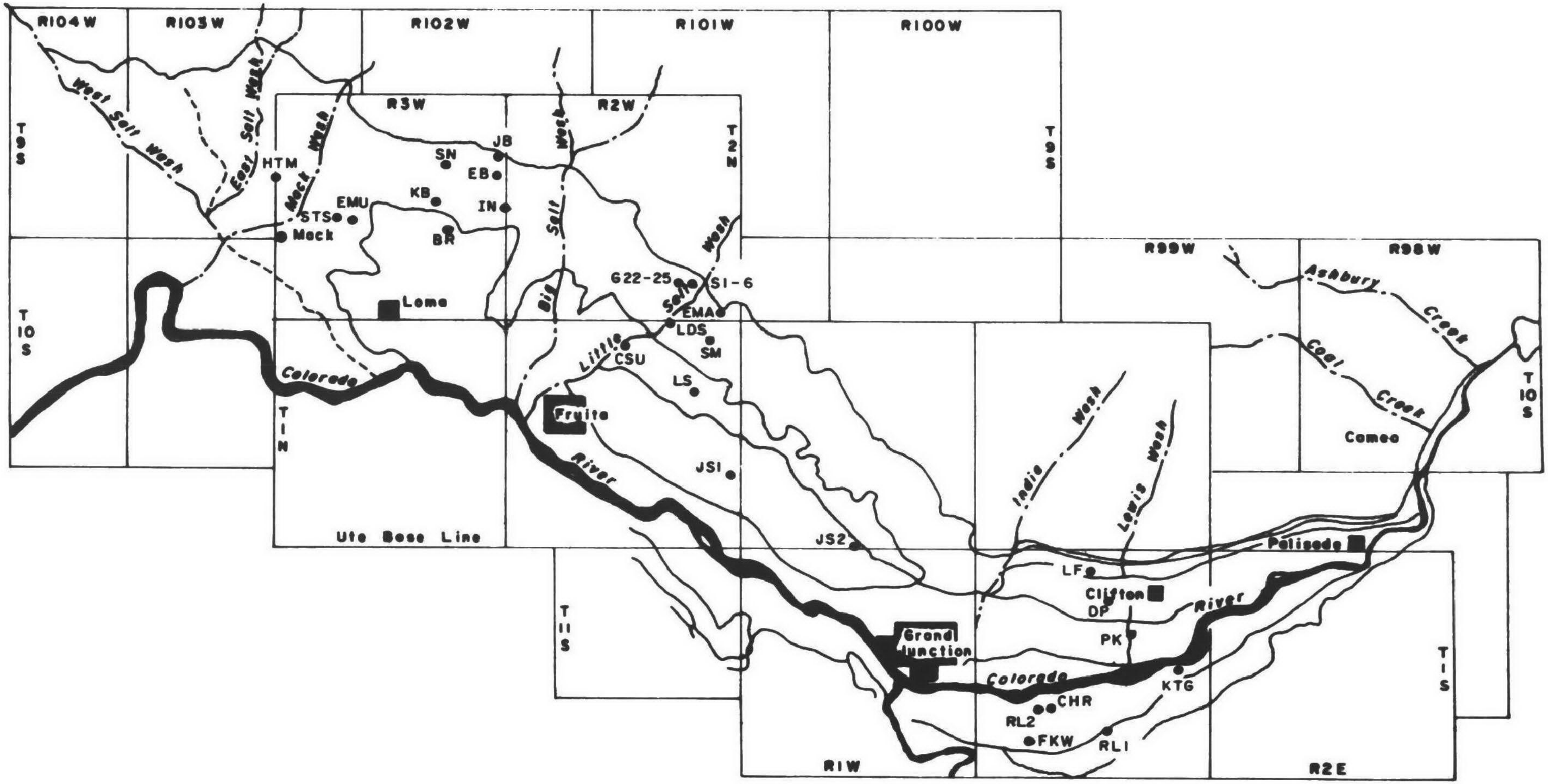

Figure 4. Location of fields sampled for chloride analysis

and where high water tables were anticipated. Sampling was, however, restricted to fields where only one (or in some cases, two very similar) soil series was represented. Because preliminary results from the intensive study area appeared to contradict the earlier results of Skogerboe, et. al. (1972, 1974), several fields east of Grand Junction, including Skogerboe's study area, were sampled by the chloride profile technique to determine whether percolation rates differ as greatly as the two studies suggested.

Direct Measurement of Deep Percolation

Following analysis of the soil chloride profiles, site selection for installation of vacuum extractors proceeded. Vacuum extractors were not installed in the eastern half of the valley because 1) Skogerboe's (1972, 1974) studies were quite intensive in that area, 2) water tables in that area are generally high, precluding the use of extractors, 3) limited labor, and 4) preliminary evaluation of chloride profiles indicated that percolation in the eastern valley is indeed higher (as reported by Skogerboe) than in the western valley. The requirement that water tables be significantly below the root zone and that electrical power be reasonably available limited the number of suitable sites.

In addition to the intensive study site, vacuum extractors were installed on five farms representing the Billings, Ravola, and Fruita soil series (see Figure 5). Subsequent high water tables did cause problems in some areas as will be discussed in a later section.

Measurements of Irrigation Application and Runoff

Again utilizing soil chloride analyses as a guide, but not restricting sites to those apparently well drained, 27 locations on 15 farms were instrumented to measure irrigation application and tailwater runoff. As shown in Table 4, these farms represent all the major soil series discussed earlier. Typical of most irrigated land in the valley, the topography at all sites is quite flat, with the slope of only one field (CSUW) exceeding 1.5 percent. Eight of these fields (all except CHR, CSUC, CSUW, RTG, GIE, FOR and SM) were provided with access tubes to allow periodic soil water measurement with neutron attenuation equipment. Again, no attempt was made to evaluate inflow-outflow in the area of Skogerboe's earlier studies. As shown in Figure 6, these measurements were confined to the western end of the valley, except for three sites on Orchard Mesa south of the Colorado River.

Evapotranspiration

To compute a water balance for each field, the ARS Irrigation Scheduling Program was used to simulate ET at each of the inflow-outflow study areas. Because of the proximity of evapotranspiration

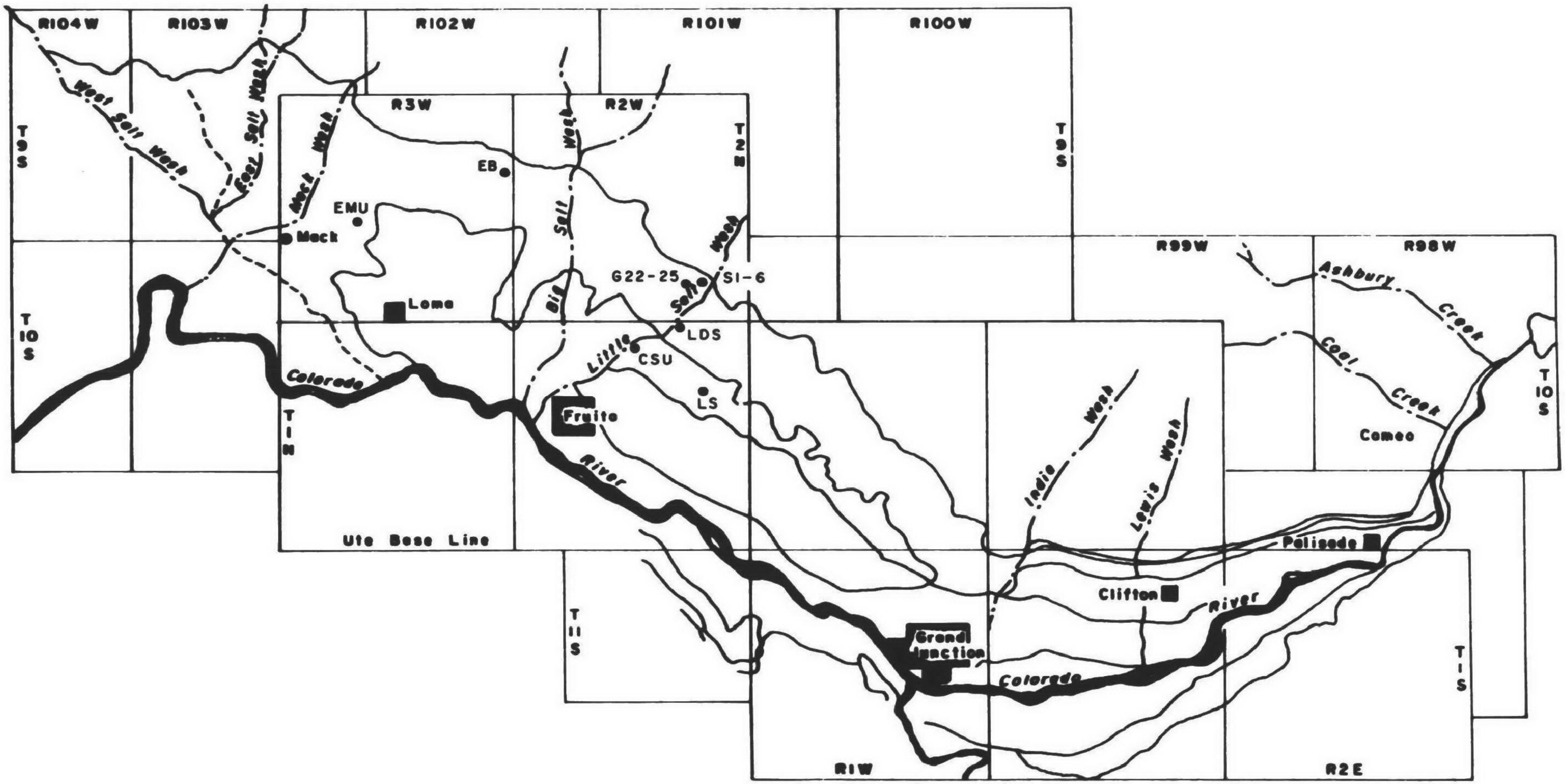

Figure 5. Location of vacuum extractors

Table 4. Irrigation application and tailwater runoff studies.

Site	Soil Type	Slope	1975 crop
EB	Ravola cl	.015	Barley
CHR	Hinman cl	.0047	Corn
CSUB	Ravola vfsl	.0053	Beets
CSUC	Ravola cl	.0065	Corn
CSUW	Chipeta-Persayo scl	.0168	Grass
FOR	Billings sltcl	-	Corn
FKW	Hinman cl	.0059	Corn
G 22-25	Ravola l	.014	Corn
GIE	Fruita cl	-	Corn
HTM	Mack (Mesa) cl	.010	Corn
LDS	Ravola vfsl	.0065	Corn
LS	Billings scl	.0058	Corn
RTG	Mesa cl	-	Corn
SM	Ravola vfsl	.0079	Corn
STS	Fruita cl	.0080	Corn

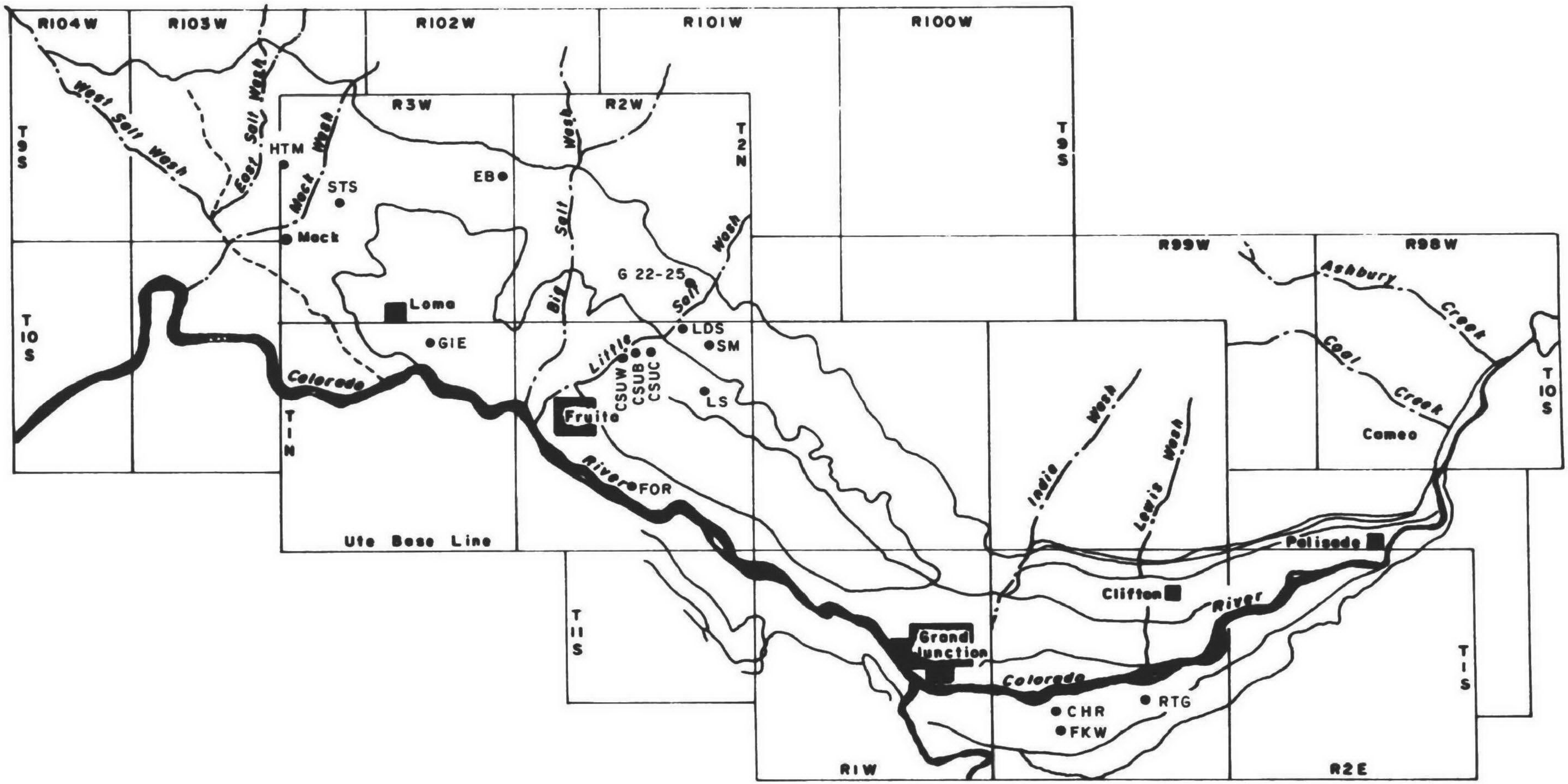

Figure 6. Location of irrigation application and tailwater runoff studies

study areas to the intensive study area, climatic data from that area were used in all computer simulations. To minimize problems of advective energy, the weather station was planted to a perennial grass and irrigated by gravity methods to provide soil cover. The weather station included a Class A evaporation pan, totalizing anemometer, integrating pyranometer, standard and recording rain gauges, and, in the standard Cotton Region shelter, a hygrothermograph and current, maximum and minimum thermometers.

An electronically weighing lysimeter (6 ft x 7.5 ft x 5 ft deep) was installed as a part of the original study with the Bureau of Reclamation. This lysimeter was installed under the sprinkler (plot S-2, 5% leaching). Because these plots were irrigated as often as four times daily, a practice unique to the research plots, it was desired that ET be determined directly under conventional furrow irrigation to refine the crop coefficient curves used in the scheduling program. Thus, a weighing lysimeter was installed and planted to corn in the furrow irrigated plots (G-25) at the intensive study site and two lysimeters, one planted to corn and the other to beets, at the Colorado State University Experiment Station near Fruita (CSUB, CSUC).

The potential ET, to which the above mentioned crop coefficient curves are applied, is defined as the ET from a well irrigated crop having a full canopy, such as alfalfa or grasses. An additional lysimeter was installed at the CSU Station by filling the lysimeter tank with a monolith taken from an established field of alfalfa. This lysimeter served for recalibration of the potential ET calculations in the scheduling program. As the 1975 season progressed, it became apparent that estimates of net radiation calculated from total solar radiation measurements were in error. A Fritschen net radiometer was installed near the alfalfa lysimeter to provide direct net radiation measurements and allow adjustment of that portion of the program.

Lateral and Canal Seepage

At least four previous investigators, reported by Skogerboe and Walker (1972), have attempted to conduct seepage measurements on the delivery canals in the Grand Valley. ARS's interest in conducting such studies as part of the current project arose from the need to more accurately define the local hydrogeology in the vicinity of the intensive study area. Results from the current study are combined with those of previous investigators in subsequent seepage analyses.

Two ponds were constructed immediately following the 1974 irrigation season by temporarily damming the Government Highline Canal at 20 Road, Little Salt Wash and Adobe Wash (see Figure 7), a total length of 17,800 feet. These two sections of canal were underlain by alluvial material and weathered shale, respectively. Seepage rates were monitored for seven days following ponding.

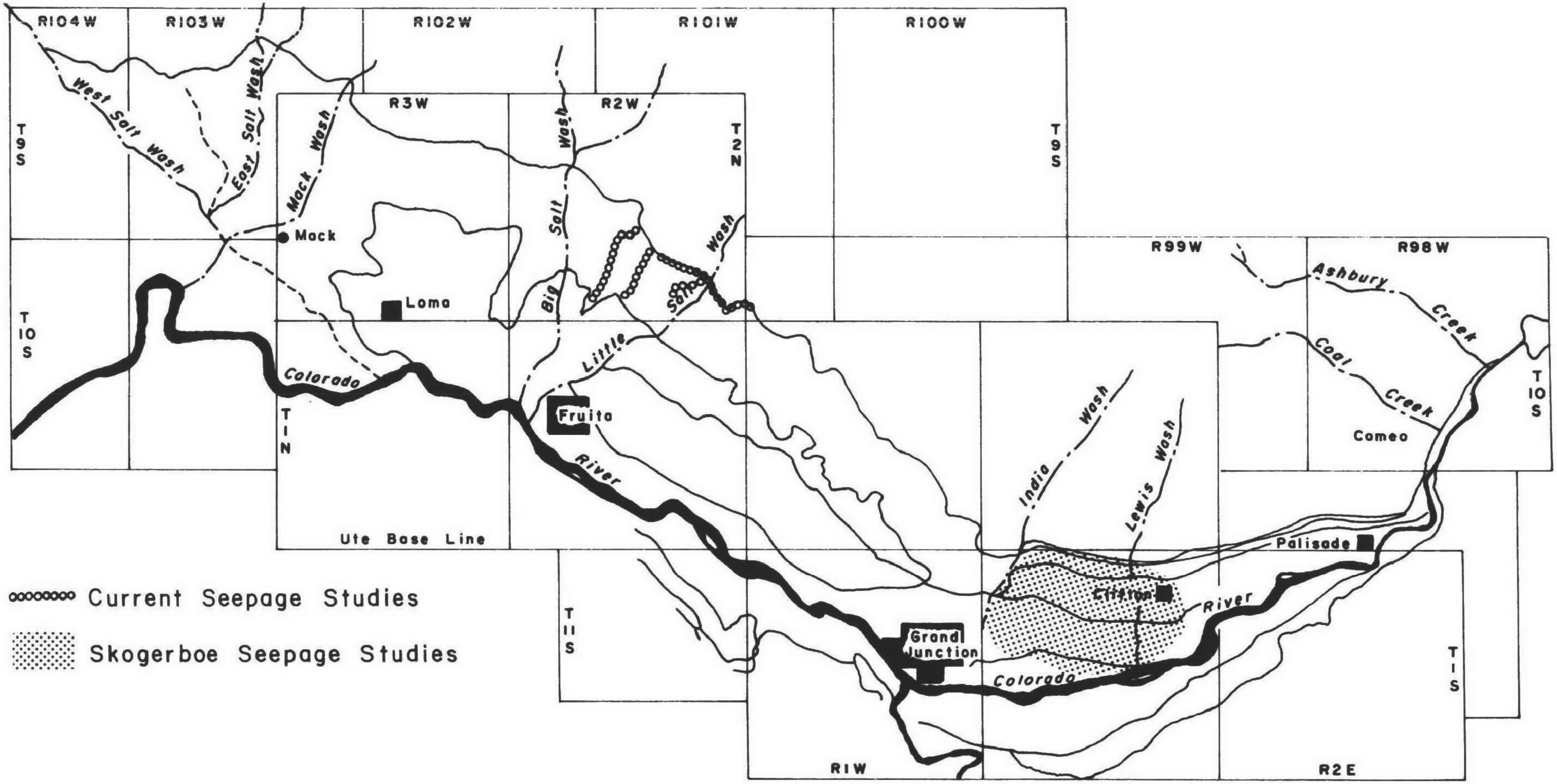

Figure 7. Location of canal and lateral seepage studies

To determine the relative importance of seepage from the smaller laterals, a total of eleven ponds were constructed on three laterals served by the Government Highline Canal in the fall of 1975. These ponds, totaling 6100 feet in length, were on laterals 30, 33, and 35 cut through Ravola fine sandy loam overlying alluvium, Fruita clay loam, and shale outcrops, respectively.

Earlier ARS measurements with seepage meters indicated decreasing seepage rate as the irrigation season progresses. Further ponding tests were conducted in laterals 30 and 35 prior to the start of the 1976 irrigation season. Four ponds, each 100 feet in length, were constructed. Since diversion of river water down the canal was impractical at this time of year, water was hauled by tank truck from the Colorado River to fill these ponds for the spring seepage tests.

Drain Flows and Ground Water

As a part of the current study, it was desired to attempt to determine the route by which percolation and seepage return to the river. During the winters of 1974-75 and 1975-76, flow measuring flumes were installed in the major washes, as shown in Figure 8. The first winter, flows were measured approximately weekly on Little Salt, East and West Big Salt, Adobe and Persigo washes. During the winter 1975-76, a total of 21 measuring stations were operated on nine washes, including the five above plus Hunter, Indian and Lewis Washes and Leach Creek. Seven of these washes had more than one flume installed. Samples were taken for chemical analysis at each flume whenever the flow rate was determined.

The winter wash flows are quite small compared with normal canal spillage or runoff from irrigation and summer thunderstorms, requiring relatively small measuring flumes. Therefore, the flumes could not be left in place during the irrigation season.

During the summer of 1974, a geologic study was conducted in the vicinity of Little Salt and Adobe Washes. Electrical resistivity techniques and 23 drill holes were used to map the bedrock in the area (Schneider, 1975). Most of the drill holes were fitted with perforated plastic casing, through which groundwater levels have been measured and samples collected periodically for chemical analysis.

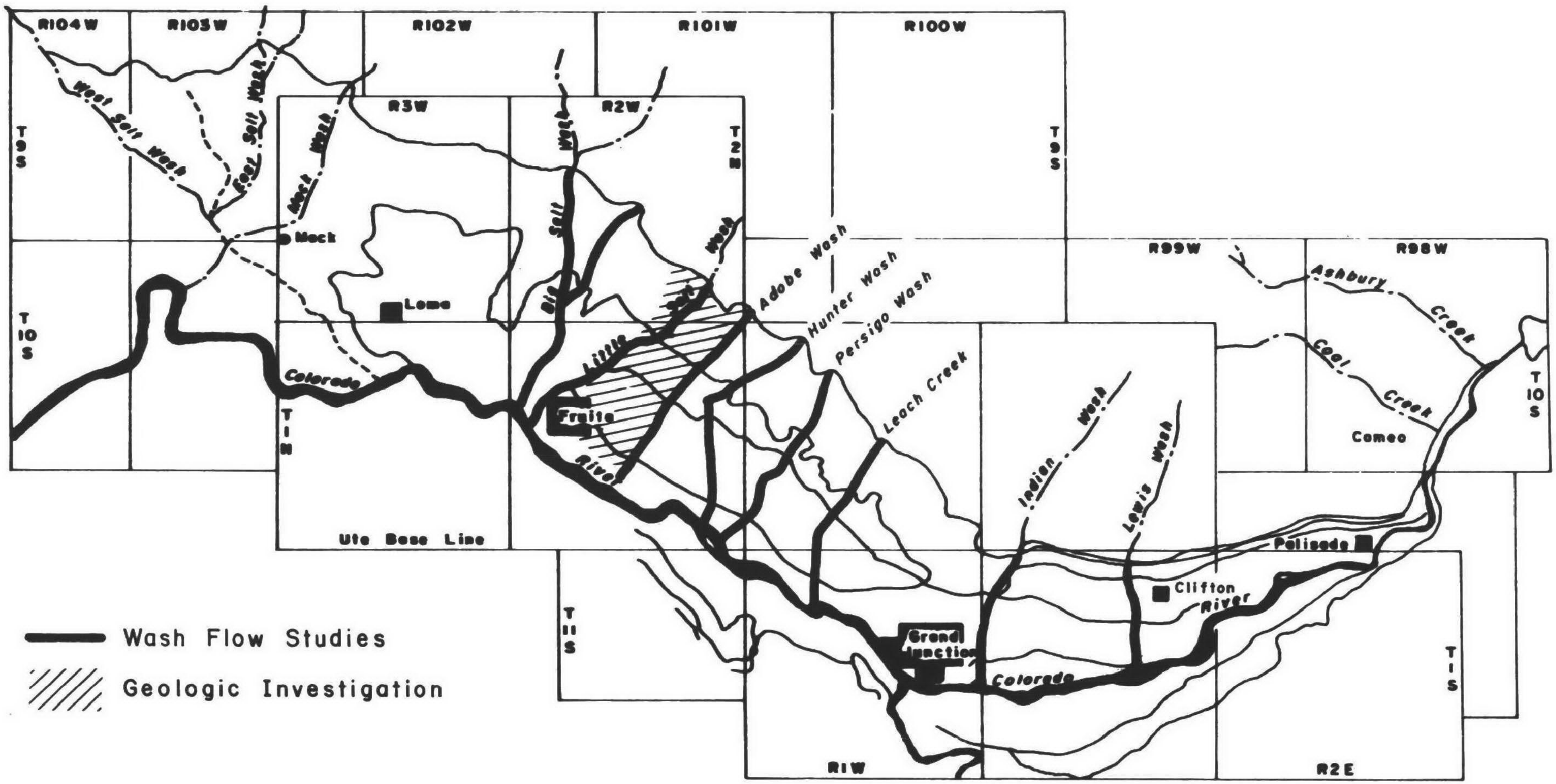

Figure 8. Location of wash discharge studies and geologic investigation

SECTION VII

RESULTS

Because the current study is quite closely related to ongoing studies conducted for the Bureau of Reclamation, it is both difficult and inappropriate to attempt to separate the results of the two research programs. Therefore, where they add to the objectives of this study, data collected from the USBR study will be used to help satisfy the objectives of this study. Likewise, certain of the data collected specifically under this study will be reported to the USBR in support of that program.

As mentioned earlier, the surficial geology of the Grand Valley is quite complex, resulting in over 70 soil series classifications. Even within a particular soil series, considerable soil variability is encountered. Irregular bedrock topography, bedrock fractures, clay layers and sand lenses are frequently encountered. As a result, high water tables, perched groundwater, artesian conditions and substantial lateral flow may occur, especially during the irrigation season. Because of the many variables encountered, it is impossible to precisely quantify the hydrologic parameters of the valley as a whole. Efforts have been made to collect data from farms covering a range of conditions, but results must be interpreted with full understanding of the statistical variability expected.

Chloride Sampling to Infer Leaching Fraction

Because chloride salts are quite soluble, the primary source of chlorides in soils with a history of leaching due to irrigation is from the irrigation water itself. Figure 9 illustrates a typical soil chloride profile under conditions of steady irrigation, evapotranspiration and leaching. At the soil surface, the chloride concentration in the soil water is essentially that of the irrigation water. The Cl^- concentration increases with depth as water is extracted by the plant, until, below the root zone no further concentration occurs. Thus, the ratio of concentration in the irrigation water to that below the root zone is equal to the fraction of the applied irrigation water percolating below the root zone (i.e. the leaching fraction).

Since water movement in partially saturated soils is quite slow, it can be expected that the chloride concentration at 120 to 150 cm depth represents an integrated average leaching history for several months or years previous to sampling. Thus, to properly calculate the leaching fraction, one must use the average chloride concentration of the water applied. Table 5 shows that the chloride concentration of irrigation water delivered at the intensive study site (G22-25, S1-6) increases substantially as the season progresses. Table 6 shows the mean concentration for the furrow plots at this

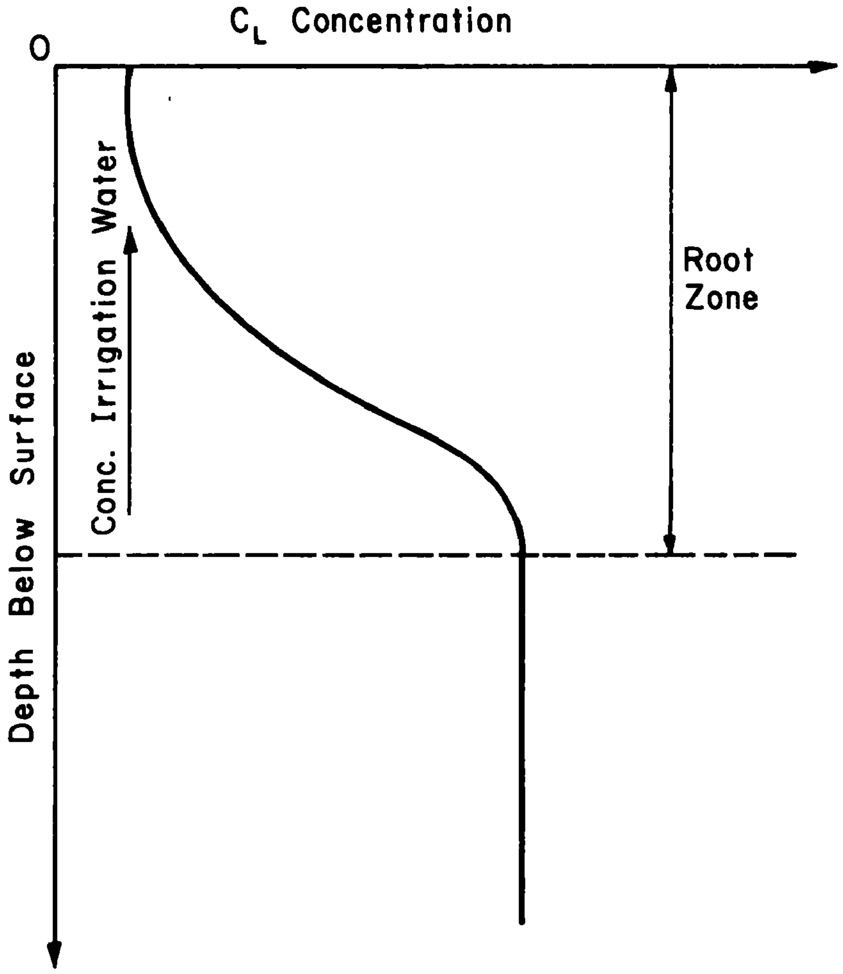

Figure 9. Hypothetical Cl^- concentration profile of soil solution under leaching conditions

Table 5. Composition of irrigation water at intensive study site

Date	EC mmho/cm	Cl^- meq/ℓ
6/27/73	0.35	0.7
7/31/73	0.63	2.1
8/14/73	0.72	2.6
9/20/73	1.08	4.7
6/5/74	0.35	0.8
6/18/74	0.44	1.2
6/20/74	0.35	0.9
7/3/74	0.49	1.5
7/17/74	0.75	2.8
7/31/74	0.82	3.0
8/12/74	0.90	3.9
8/29/74	1.08	4.9
6/18/75	0.34	1.0
7/10/75	0.36	0.8
7/25/75	0.52	1.5
8/5/75	0.69	2.1
8/11/75	0.78	3.0
8/25/75	0.91	3.7
9/2/75	0.95	4.2
9/15/75	1.09	4.9
9/22/75	1.02	4.5
10/7/75	1.03	5.1

site for each of the three years of data available, weighted by the depth of infiltration at each irrigation (i.e. at each Cl^- concentration). Since the chloride profile technique is based on the assumption that Cl^- concentration below the root zone is the result of at least several months past irrigation history, it is reasonable to assume that the analyses from a set of samples in the above fields would change little over the three year period. If the Cl^- concentration of these samples were 15 meq/l, then the indicated leaching fraction would range between .127 and .202, depending on the irrigation water analysis used for computations. The potential error in using analyses from a single sample of irrigation water is even greater. If the leaching fraction resulting in the same 15 meq/l soil solution concentration were calculated from individual irrigation water analyses (Table 5), the apparent leaching fraction would range from 0.053 to 0.340.

Table 6. Weighted chloride concentration in irrigation water.

Year	Plots	Cl^- meq/l
1973	S1-6	2.13
	G22-25	2.36
1974	S1-6	3.03
	G22-25	2.30
1975	S1-6	1.97
	G22-25	1.90
Average	S1-6	2.38
	G22-25	2.19

To be theoretically correct, application of the method should take into account the water applied by precipitation, as well. The average annual precipitation in the Grand Valley is 21 cm (Skogerboe, et. al., 1974), distributed approximately uniformly through the year. If one assumes that half the winter precipitation (12.5 cm) evaporates, and that the summer precipitation reduces the irrigation needed to meet the total year round average ET of 91.5 cm, the weighted average Cl^- shown in Table 6 would be reduced from 2.19 to 1.77 meq/l. For the same soil solution concentration of the previous example (15 meq/l) the calculated leaching fraction is 0.146 when irrigation water concentration alone is used, 0.118 when the effect of precipitation is included.

One factor further complicating application of the chloride sampling technique in the Grand Valley is the observation (to be discussed in a later section) that the infiltration rate of most soils in the valley is two to three times greater during the first irrigation of the season than during subsequent irrigations. This, combined with the practice of extended irrigation to "sub across" for germination, undoubtedly results in relatively high deep percolation during the first irrigation. Since the Cl^- concentration is quite low at this time, and since the soils of the valley are characterized by deep cracking allowing rapid percolation, it is possible that this early irrigation results in a flushing of Cl^- from the lower profile resulting in an unexpectedly low Cl^- concentration.

These factors, which complicate calculation of leaching fraction from soil chloride profiles, tend to reduce the chloride concentration below the root zone below that expected from analysis of the irrigation water. As a result, estimates of leaching fraction are higher than the actual leaching fraction. Perhaps from this standpoint alone, the method is a useful tool in that it gives an upper limit to estimates of deep percolation. With these points in mind, we proceed to analyze the results of the current chloride profile studies.

More than 1500 individual soil samples were analyzed for Cl^- concentration in a 1:1 soil solution extract. To calculate leaching fraction, it is necessary to convert these concentrations to the concentration at which water is mobile under gravitational forces. Results of soil water characteristic determinations at the intensive study site indicate that the water content at field capacity (1/3 bar suction) is about 20% on a dry weight basis. This figure was used to normalize all Cl^- data collected. Use of a single water content to normalize all samples undoubtedly shifts the normalized values for a particular site somewhat. However, the overall error introduced by using the common factor is minimal, since all soils (except on Orchard Mesa) are quite fine textured. The soils at the intensive study site, for which the 20% field capacity was determined, are intermediate to the texture of the other soils studied. Table 7 shows the average Cl^- concentration as a function of depth. Each value shown is the average of all samples collected at a particular sampling time. Leaching fraction calculations for all samples were based on the three year average Cl^- concentration of irrigation water at sites G22-25 (Table 6) corrected for the average annual precipitation as shown in the previous example. Weighted Cl^- concentration of applied water was calculated to be 1.77 meq/l. Nineteen of the 71 profiles sampled show an "inverted" chloride profile (indicated by asterisk) i.e., higher Cl^- concentration at the surface, decreasing with depth. Such a profile is presumed indicative of a net upward flow of water from the water table, and eventually results in salinization of the soil. No production history is available for these sites to determine whether, in fact, salinization is occurring. A calculated leaching fraction has been shown for all profiles, although if these inverted profiles are truly indicative of net upward flow, the leaching fraction is zero, and Cl^- concentration is indicative of groundwater quality.

Table 7. Chloride concentrations at 20% (dwb) soil water content

Site	Soil type	Date	No. Samples	Cl^-, meq/ℓ 0-30	30-61	61-91	91-122	122-152	Indicated leaching fraction
BR	Billings sltcl	4/74	30	38.15	17.48	10.23	11.91	5.45	*0.32
CHR I	Hinman cl	6/17/75	12	1.02	1.55	1.70	2.69	-	0.66(a)
	Hinman cl	7/8/75	12	.95	1.16	1.26	1.42	-	1.25(a)
	Hinman cl	9/18/75	15	4.24	3.47	4.12	3.43	3.79	0.47(a)
CHR II	Hinman cl	6/17/75	12	3.35	5.28	3.27	3.30	-	0.54
	Hinman cl	7/8/75	12	1.36	3.65	4.23	4.49	-	0.39
CSUB	Ravola vfsl	6/3/75	15	2.89	5.18	6.65	13.93	17.27	0.10(a)
	Ravola vfsl	11/3/75	15	8/15	3.09	4.96	4.91	8.54	0.21(a)
CSUW	Chipeta-Persayo	6/23/75	12	4.06	3.91	4.04	5.09	-	0.35(a)
	Chipeta-Persayo	6/30/75	12	3.97	2.13	2.19	2.65	-	0.67(a)
DP	Ravola	12/74	19	6.60	5.94	9.61	10.74	6.89	0.26
EB	Ravola loam	4/74	40	5.16	13.97	11.98	8.54	6.74	*0.26
EMA	Ravola	12/74	48	6.15	4.54	3.81	2.49	2.54	*0.70
EMU	Fruita cl	4/74	44	9.88	6.81	5.86	5.97	4.79	*0.37
FKW I	Hinman cl	6/17/75	12	4.80	6.19	5.12	6.23	-	0.28(a)
	Hinman cl	6/24/75	12	4.79	4.21	5.53	4.06	-	0.44(a)
FKW II	Hinman cl	6/13/75	12	4.68	5.31	5.38	5.81	-	0.30
	Hinman cl	6/24/75	12	2.91	4.29	4.69	4.54	-	0.39
	Hinman cl	9/18/75	13	5.27	9.65	5.95	4.29	2.78	*0.64
FKW III	Hinman cl	6/24/75	12	7.25	7.42	7.61	7.96	-	0.22
	Hinman cl	9/18/75	13	6.10	6.65	6.59	3.03	2.96	*0.60
G22	Ravola loam	12/74	5	10.30	7.81	8.12	17.82	13.99	0.13
	Ravola loam	8/18/75	29	2.80	2.20	2.62	2.61	2.24	0.79
G23	Ravola loam	12/74	5	3.87	3.66	4.28	3.13	0.58	*3.05
	Ravola loam	8/18/75	30	5.16	2.51	1.45	1.49	1.72	*1.03
G24	Ravola loam	12/74	15	2.63	5.21	6.26	7.28	8.85	0.20(a)
	Ravola loam	8/18/75	57	3.32	2.15	2.60	3.24	3.63	0.49(a)
G25	Ravola loam	12/74	15	3.62	3.59	4.91	9.79	7.77	0.23
	Ravola loam	8/18/75	60	5.31	5.84	6.72	7.57	8.15	0.22

Table 7. Chloride concentrations at 20% (dwb) soil water content
Page 2

Site	Soil type	Date	No. Samples	Cl^-, meq/ℓ					Indicated leaching fraction
				0-30	30-61	61-91	91-122	122-152	
HTM	Mack(Mesa) clay	6/24/75	12	2.83	7.29	5.99	4.11	-	0.43
	Mack(Mesa) clay	9/12/75	15	3.64	3.82	3.90	4.02	3.57	0.50
IN	Billings sltcl	4/74	18	23.15	11.49	8.72	6.55	8.30	*0.21
JB	Ravola loam	4/74	45	8.90	9.53	9.19	10.61	10.24	0.17
JS1	Billings	12/74	50	8.44	35.92	60.30	103.05	79.15	0.02
JS2	Ravola vfsl	12/74	40	19.56	19.93	26.39	35.58	34.10	0.05
KB	Billings cl	4/74	45	11.23	7.29	9.36	10.89	12.79	0.14
LDS	Ravola vfsl	12/74	47	7.35	11.67	17.07	18.57	17.53	0.10(a)
	Ravola vfsl	9/26/75	15	4.90	6.76	3.12	3.84	4.21	0.42(a)
LF	Ravola	12/74	38	11.57	7.05	8.48	13.04	14.43	0.12
LS	Billings sltcl	12/74	48	5.37	6.60	5.20	6.01	5.40	0.33
	Billings sltcl	9/19/75	15	4.12	4.99	8.16	8.87	8.77	0.20
RL1	Mesa clay	12/74	21	3/47	3.79	4.80	3.95	7.65	0.23
RL2	Hinman cl	12/74	46	5.98	7.47	6.67	5.53	6.26	0.28
RTG I	Mesa cl	6/11/75	9	10.88	5.40	18.84	7.58	-	0.09
	Mesa cl	6/16/75	12	7.33	9.57	6.92	8.10	-	0.22
RTG II	Mesa cl	6/11/75	12	8.35	9.90	10.71	8.09	-	0.22(a)
	Mesa cl	6/16/75	12	3.44	3.57	5.21	4.68	-	0.38(a)
RTG III	Mesa cl	9/12/75	15	4.33	5.54	3.62	4.90	2.76	0.64
S1	Ravola loam	12/74	15	2.08	6.58	6.32	11.64	8.91	0.20
	Ravola loam	8/13/75	25	3.71	3.43	6.54	6.60	6.49	0.27
S2	Ravola loam	12/74	15	2.64	6.78	10.14	15.14	12.09	0.15
	Ravola loam	8/13/75	25	5.24	5.38	8.24	10.89	12.91	0.14
S3	Ravola loam	12/74	15	2.77	7.33	7.71	8.35	9.33	0.19(a)
	Ravola loam	8/13/75	25	3.40	3.08	3.07	4.56	4.82	0.37(a)
S4	Ravola loam	12/74	15	2.95	6.30	6.53	8.15	12.56	0.14(a)
	Ravola loam	8/13/75	24	3.52	4.27	5.97	7.97	4.22	0.42(a)
S5	Ravola loam	12/74	15	2.67	6.52	9.14	12.44	11.34	0.16
	Ravola loam	8/13/75	25	3.17	4.80	8.72	10.87	8.43	0.21
S6	Ravola loam	12/74	15	2.03	5.64	8.59	13.54	16.58	0.11
	Ravola loam	8/13/75	21	3.62	3.42	3.11	6.03	10.93	0.16

Table 7. Chloride concentrations at 20% (dwb) soil water content
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Site	Soil type	Date	No. Samples	Cl^-, meq/ℓ					Indicated leaching fraction
				0-30	30-61	61-91	91-122	122-152	
SM	Ravola vfsl	6/16/75	11	32.23	13.99	11.85	13.17	-	*0.13
SN	Ravola vfsl	4/74	10	31.45	9.50	11.53	4.40	4.60	*0.38
STS I	Fruita cl	6/10/75	12	7.25	5.70	3.28	4.81	-	*0.37
	Fruita cl	6/13/75	12	5.67	5.04	4.89	3.47	-	*0.51
	Fruita cl	6/20/75	9	8.15	6.40	4.14	3.92	-	*0.45
	Fruita cl	9/19/75	14	12.90	6.16	2.77	4.21	6.09	*0.29
STS II	Fruita cl	6/17/75	12	6.09	5.18	3.94	3.88	-	*0.46
	Fruita cl	9/25/75	15	6.55	6.04	3.85	3.15	2.48	*0.71
STS III	Fruita cl	6/16/75	12	5.94	5.64	3.83	4.32	-	*0.41(a)
	Fruita cl	6/25/75	12	7.66	4.40	4.03	2.74	-	*0.65(a)

* Indicates inverted profile, indicative of net upward water flow

(a) LF from two sampling dates differ by more than one standard deviation

At several sites, Cl^- samples were collected periodically to test the assumption that Cl^- concentration below the root zone responds only to long term changes in management. In some instances (e.g. CSUW, FKW I, RTG II, STS III) leaching fractions calculated from samples taken immediately before and immediately after a single irrigation differed by more than their respective standard deviations. Further sites showed significant changes within a year, suggesting that the Cl^- concentration below the root zone is influenced by short term events such as flows into surface cracks.

Few successive samplings showed close correspondence of calculated leaching fractions (e.g., CHR II, LS, RTG I), even though the values did not show statistically significant differences. The mean value of individual standard deviations of leaching fraction exceeded 0.1, or about 1/3 of the mean leaching fraction (see Table 8). The standard deviation of the mean was even greater at 0.22, indicating a high degree of variability within individual fields. Even greater variability was observed from field to field. Detailed statistical analyses show that 47 soil profiles per field would be needed to reduce standard deviations within an individual field to within ± 10% of the calculated leaching fraction. To characterize the entire valley would require sampling an estimated 104 fields, for a total of approximately 25,000 individual soil samples. These numbers presume that no change in calculated leaching fraction occurs with time, which is an unsubstantiated assumption at this time.

From Table 8, one can observe apparent differences in the mean leaching fraction calculated for different soil types, although there is no statistical difference between these mean leaching fractions. The relative magnitudes do correspond somewhat with measured

Table 8. Average leaching fraction as calculated by chloride profile technique.

Soil type	Leaching fraction	Standard deviation	Remarks
Billings	0.206	0.134	(a)
	0.223	0.118	(b)
Chipeta-Persayo	0.510	0.226	(a)
Fruita	0.469	0.136	(b)
Hinman	0.475	0.287	(a)
	0.497	0.268	(b)
Mack(Mesa)	0.339	0.181	(a)
Ravola	0.231	0.157	(a)
	0.361	0.536	(b)
All samples	0.308	0.217	(a)
	0.388	0.392	(b)

(a) Includes only "normal" chloride profiles
(b) Includes all samples analyzed, some or all "inverted" chloride profiles

cumulative infiltration rates, which will be discussed later, with Billings and Ravola soils having the least infiltration, Chipeta-Persayo, Hinman, and Mesa soils having the highest infiltration rate.

The chloride profile technique for calculation of leaching fraction has apparently proven successful for other investigators, particularly in the desert Southwest where precipitation is negligible, irrigation is applied practically year around, and water quality probably varies slowly because of reservoir impoundment or pumping from groundwater aquifers. However, the usefulness of the method in the Grand Valley is not obvious because the direct river flows used for irrigation vary more than ten fold in Cl^- concentration over a season, annual precipitation is approximately 25% of ET, and irrigation water is applied during only about 40% of each year. Under such conditions, leaching fractions estimated by this method likely represent an upper limit of actual leaching. Based on this assumption, and assuming an average ET during the growing season of 81 cm (32 inches), the maximum expected deep percolation loss for the 56,000 irrigated acres is 66,400 acre feet annually. The actual deep percolation is probably considerably less as will be discussed subsequently.

Direct Measurement of Water Balance Components

Furrow Irrigation Inflow-Outflow Studies

To determine efficiency of furrow irrigation in the Valley, 27 fields on fifteen farms were instrumented to measure irrigation water application, tailwater runoff, and, at selected sites, soil water storage and deep percolation. Table 9 summarizes the instrumentation installed at each site, and the number of irrigations studied during each growing season. During 1975, at least every other irrigation was studied at each site. Continuing studies during the 1976 growing season are included, particularly for the first irrigation of the season, where analyses of results have been completed.

During initial site selection, it was intended to obtain half the cooperators from the group participating in the USBR's Irrigation Management Services (IMS). However, of higher priority was the necessity to obtain sites in fields under a single soil type and which were not expected to have high water table problems. Further observations led to the conclusion that the present delivery system and lack of water measurement devices for water delivery would negate attempts to determine the effect of the current IMS on improved irrigation efficiency. Under the present conditions in most of the valley, farmers could benefit from the time of irrigation aspects of the service, but generally have no way to determine accurately the net amount of application. Thus, final site selections were made without consideration of participation in the irrigation scheduling services available.

Table 9. Furrow irrigation studies, instrumentation summary

Field Designation	Soil Type	Vacuum Extractors	Neutron Tubes	Orifice Box	Inflow Flume	Runoff Flume	No. Sites	Number of Irrigations Studied 1974	1975	1976
HTM	Mack(Mesa) cl		X	X		X	1		7	
STS	Fruita cl		X	X		X	3		6	2
EB	Ravola cl	X	X	X		X	1		1	2
CSUW	Chipeta-Persayo			X	X	X	2		2	
CSUB	Ravola	X	X	X		X	1		10	10
CSUC	Ravola			X		X	1		1	
LDS	Ravola vfsl	X	X	X		X	1		4	1
G22-25	Ravola loam	X	X	X	X	X	4	42	16	12
SM	Ravola vfsl						1		1	
LS	Billings sltcl	X	X	X		X	2		6	6
CHR	Hinman cl			*	X	X	1		5	
FKW	Hinman cl		X	X		X	3		9	5
RTG	Mesa cl			*			3		8	
GIE	Fruita cl			X		X				9
FOR	Billings sltcl			X		X				4
									TOTAL 160	

*Individual furrow flumes used

Except for the G22-25 plots and 1976 irrigation on the CSUB plots, all sites were irrigated by the farmer himself at the same time and rate of application as used on the remainder of the field.

Table 10 shows the pertinent flow data for all irrigations studied. The average application time for irrigations studied was 27.7 hours, and bears little relation to either length of run or stream size. The first irrigation, when required to obtain germination, is typically quite long to allow wetting to the top of the seedbed. The average total application for all irrigations was 7.2 inches, with 33.6% of applied water leaving the field as tailwater runoff. Thus, the average net application was 4.8 inches. Net applications were extremely high at the CHR and early irrigation at FKW sites, even though large stream sizes were used. Tailwater runoff ranged from zero to in excess of 80% of applied water.

During the season, spot measurements of furrow cross section and flow resistance were made. This was done by installing a small flume at two or three locations in a furrow to determine the flow rate and then measuring the width and depth of flow at several points below the flume. The cross sections were considered rectangular since the width was greater than five times the depth in all cases. Table 11 lists hydraulic characteristics of several sites. Computed surface storage varied between .1 and .2 inch during irrigation in most cases.

Intake rates for the different soil types were calculated from the foregoing data and are listed in Table 12. Rates are expressed in terms of the coefficients in the equation:

$$I = at^b$$

where I is the cumulative intake, inches
t is intake opportunity time, hours.

The coefficients, a and b, are derived from a representative cumulative intake rate curve, based on all monitored irrigations of the soil in question.

Insufficient data were obtained on the Ravola clay loam soil for intake analysis. Only two irrigations were obtained on the Persayo soil. In general, the Billings, Ravola and Fruita soils had similar intake characteristics and the variation between irrigations was greater than the variations between these soil types. The Hinman and Mesa soils had generally higher intake characteristics, however. Table 12 also contains values of cumulative intake at 12 and 24 hours, based on the average coefficients from 1975 and 1976 tests. Twelve-hour intake for irrigations other than the first varies only from 1.57 inches to 3.58 inches, except for the Hinman and Mesa soil, found east of the river on Orchard Mesa, which have higher rates.

Analyses from early 1976 irrigations at 18 sites are shown in Table 13. The 24 hour cumulative intake for the first irrigation

Table 10. Furrow irrigation studies

Site	Date	Run L, ft	Stream size q, gpm	Slope ft/ft	Appl. Time, T, min	Advance Time, min	Gross Appl. Depth, inches	Meas. Runoff inches
CHR I	5/21/75	1100	26.13	0.0047	1404	840	21.4	0.6
	6/24/75		23.22		1410	600	19.1	0.6
	7/21/75		16.84		1842	480	18.1	2.1
	8/12/75		19.37		1230	270	13.9	2.6
	8/29/75		12.53		1368	240	10.0	1.5
CSUB	6/19/75	710	2.21	0.0053	1440	165	3.5	2.1
	7/3/75		4.40		1086	225	5.4	3.3
	7/22/75		4.02		1056	105	4.8	3.6
	8/1/75		3.72		642	165	2.7	1.4
	8/9/75		3.69		1536	105	6.4	4.2
	8/19/75		3.80		1374	135	5.9	4.0
	8/29/75		5.62		1182	135	7.5	5.9
	9/11/75		3.86		1056	225	4.6	3.3
	9/25/75		2.47		1506	195	4.2	2.6
	10/7/75		2.95		510	105	1.7	0.9
CSUB I	5/5/76	710	7.20	0.0053	1350	600	8.8	2.2
	6/3/76		6.66		1320	120	8.0	3.6
CSUB II	5/5/76	710	10.30	0.0053	1260	300	5.9	1.5
	6/4/76		5.92		2850	120	7.6	4.8
CSUB III	5/6/76	720	8.08	0.0053	1440	360	5.2	1.8
	6/6/76		8.98		1470	120	5.9	3.8
CSUB IV	5/19/76	730	2.53	0.0053	2430	1020	5.4	1.0
	6/7/76		9.61		1410	120	6.0	4.4

Table 10. Furrow irrigation studies
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Site	Date	Run L, ft	Stream size q, gpm	Slope ft/ft	Appl. Time, T, min	Advance Time, min	Gross Appl. Depth, inches	Meas. Runoff inches
CSUB V	5/7/76	730	7.20	0.0053	1230	600	7.8	1.1
	6/8/76		9.71		1440	120	6.2	4.0
CSUC	5/22/75	1120	7.75	0.0065	1374	270	6.1	2.9
CSUW I	6/23/75	500	7.33*	0.0168	1506	330	17.7	6.1
CSUW II	10/16/75	500	3.76	0.0168	1260	60	7.6	6.4
EB	6/13/75	900	7.11*	0.015	1440	75	7.3	4.9
	4/18/76		7.76		5670	105	19.6	12.1
	6/9/76		12.80		1380	134	7.9	1.5
FOR	4/14/76	1280	14.36		1380	940	9.9	.4
	5/25/76		14.15		1470	885	10.4	1.2
	6/17/76		10.86		1440	1000	7.8	1.1
	6/28/76		12.45		1380	820	8.6	1.3
FKW I	6/18/75	1280	15.33	0.0059	1470	225	11.3	4.1
	4/16/76		16.42	0.0059	1830	760	21.9	1.9
	6/5/76		19.22		690	81	4.8	.7
	6/18/76		23.51		690	90	5.9	1.8
	7/2/76		16.62		780	78	9.5	7.8
	7/16/76		12.72		1320	104	6.1	1.3
FKW II	6/20/75	1280	10.45	0.0059	1260	270	6.6	2.2
	7/13/75		6.23		1536	1170	4.8	.7
	7/31/75		14.97		1506	270	11.3	6.6
	8/19/75		8.89		1122	345	5.0	1.3
	9/1/75		8.00		798	345	3.2	.2

Table 10. Furrow irrigation studies
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Site	Date	Run L, ft	Stream size q, gpm	Slope ft/ft	Appl. Time, T, min	Advance Time, min	Gross Appl. Depth, inches	Meas. Runoff inches
FKW III	6/27/75	810	13.61	0.0060	1410	210	15.2	8.1
	8/9/75		10.44		834	255	6.9	1.5
	9/4/75		7.01		702	135	3.9	1.0
G-22	7/1/75	600	5.00	0.013	1218	105	6.5	4.8
	8/27/75		3.00		1566	345	5.0	1.2
	9/11/75		3.60		1698	330	6.6	2.3
	5/19/76		4.10		2790	120	12.2	2.0
	6/16/76		4.36		1470	120	3.4	1.1
	6/24/76		4.62		2520	240	6.2	.8
G-23	7/2/75	600	4.40	0.013	1248	225	5.8	3.0
	8/12/75		3.60		1632	210	6.3	3.6
	8/26/75		3.20		1470	195	5.1	2.6
	9/12/75		3.50		1566	360	5.8	1.9
	5/17/76		4.90		2430	360	12.7	1.5
	6/17/76		5.41		1350	60	3.9	1.3
	6/26/76		6.37		1470	120	5.0	1.3
G-24	6/12/75	1200	5.60	0.014	1074	495	3.2	.5
	7/14/75		5.00		1470	420	3.9	1.4
	7/29/75		5.10		1440	435	3.9	1.3
	8/27/75		5.10		1458	480	4.0	.6
	9/11/75		5.50		1662	465	4.9	1.2
	5/19/76		7.05		2910	120	11.0	1.0
	6/16/76		8.81		1470	120	3.5	1.3
	6/24/76		9.02		2550	180	6.2	1.3

Table 10. Furrow irrigation studies
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Site	Date	Run L, ft	Stream size q, gpm	Slope ft/ft	Appl. Time, T, min	Advance Time, min	Gross Appl. Depth, inches	Meas. Runoff inches
G-25	6/13/75	1200	6.00	0.011	834	165	2.7	1.0
	8/12/75		4.70		1584	435	4.0	1.6
	8/26/75		5.00		1554	255	4.2	1.9
	9/12/75		4.90		1566	450	4.1	1.1
	5/17/76		6.50		2490	480	8.7	1.0
	6/17/76		8.83		1350	120	3.2	1.4
	6/26/76		10.11		1470	120	4.0	1.5
GIE I	4/25/76	900	8.05		3300	2075	11.8	.1
	5/16/76		6.80		1560	285	4.7	.4
	6/9/76		7.07		660	180	2.1	.2
	6/22/76		7.07		690	160	2.2	.9
GIE II	4/22/76	1260	14.29		2700	280	12.3	1.3
	5/18/76		15.77		1170	225	5.9	.5
	6/9/76		8.12		630	310	1.6	.1
	6/22/76		7.92		570	325	1.4	.1
	7/2/76		6.10		1440	220	2.8	.5
HTM	6/2/75	1140	6.00	0.01	2754	1890	9.3	.1
	7/7/75		9.09		1602	135	8.2	3.4
	7/19/75		9.60		1536	360	8.3	1.9
	7/30/75		8.99		1758	315	8.9	2.5
	8/5/75		5.20		1470	-	4.3	0
	8/21/75		9.18		1470	225	7.6	4.5
	9/3/75		9.07		1410	135	7.2	5.1

Table 10. Furrow irrigation studies
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Site	Date	Run L, ft	Stream size q, gpm	Slope ft/ft	Appl. Time, T, min	Advance Time, min	Gross Appl. Depth, inches	Meas. Runoff inches
LDS	6/5/75	1200	8.31	0.0065	1440	270	6.4	3.2
	7/3/75		7.85		2430	1080	10.2	1.6
	7/26/75		5.99		3966	3180	12.7	.2
	8/20/75		8.40		1470	750	6.6	.2
	5/22/76		9.04		3660	2255	8.9	.3
LS I	6/5/75	1250	3.84	0.0058	2688	1125	5.3	1.6
	7/2/75		5.88		1920	765	5.8	1.4
	7/21/75		8.75		1602	405	7.2	4.3
	8/5/75		7.42		2784	735	10.6	8.1
	8/26/75		6.83		2850	660	10.0	5.3
	9/9/75		6.63		2850	525	9.7	3.8
	4/28/76		5.52		1440	580	5.1	3.0
	6/14/76		3.13		1350	360	1.4	.3
	6/30/76		3.47		1020	75	1.1	.2
LS II	5/7/76	1160	14.14		1440	580	11.3	1.6
	6/16/76		15.04		2220	220	9.2	3.1
	7/6/76		12.13		2700	200	9.1	3.6
SM	6/9/75	1000	6.81	0.0079	1122	165	4.9	2.6
STS I	6/12/75	1300		0.0080		165	5.4	
	7/23/75					270	6.5	
	8/4/75					195	7.0	
	5/13/76		10.39		2940	160	9.4	2.1
	6/22/76		12.74		660	100	2.6	.6
STS II	6/14/75	1300				-	4.4	

*Computed from "Depth Applied" assuming 30 in. row spacing.

Table 11. Hydraulic characteristics of furrow flow at selected sites, 1975 average

Site	Length	Slope	Depth	Width	Area	q	v	Manning n*	Surface Storage	Width/Depth
	ft	*ft/ft*	*ft*	*ft*	ft^2	*cfs*	*ft/sec*		*in*	
G22-25	1200	.0110	.042	.68	.029	.011	.38	.049	.139	17
LDS	1200	.0065	.071	.56	.040	.013	.33	.059	.192	8
STS	1200	.0080	.086	.55	.047	.030	.64	.037	.226	6
FKW	1280	.0056	.110	.85	.093	.046	.49	.049	.446	8
LS	1200	.0058	.064	.76	.049	.033	.66	.026	.235	13

*n values computed assuming a rectangular channel.

Table 12. Measured intake rates, Grand Valley soils

1975 Tests

Soil Type	a[1/]	b[1/]	Cumulative Intake 12 hours, inches	24 hours, inches
Billings silty clay loam, B_c	0.74	0.49	2.50	3.51
Fruita clay loam, F_e	0.43	0.67	2.27	3.62
Hinman clay loam, H_b	0.63	0.70	3.59	5.83
Mack clay loam, M_a	0.60	0.58	2.54	3.79
Mesa clay loam, M_c	1.27	0.68	6.88	11.02
Chipeta-Persayo silty clay loam, P_b	0.81	0.57	3.34	4.96
Ravola very fine sandy loam, R_c	0.52	0.58	2.20	3.28
Ravola loam, R_e	0.38	0.66	1.96	3.10

[1/] Coefficients for intake equation of the form $I = at^b$ where I is cumulative intake, inches and t is intake opportunity time, hours.

Table 12. Measured intake rates, Grand Valley soils
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1976 Tests
First Irrigation

Soil Type	a[1/]	b[1/]	Cumulative Intake 12 hours, inches	Cumulative Intake 24 hours, inches
Billings	2.52	0.34	5.82	7.35
Fruita	0.83	0.64	4.03	6.26
Hinman	3.23	0.56	12.96	19.09
Ravola	0.78	0.60	3.42	5.17
Subsequent Irrigations				
Billings	1.06	0.49	3.58	5.03
Fruita	0.32	0.78	2.22	3.81
Hinman	0.57	0.72	3.43	5.66
Ravola	0.21	0.82	1.57	2.77

[1/] Coefficients for intake equation of the form $I = at^b$ where I is cumulative intake, inches and t is intake opportunity time, hours.

Table 13. Measured intake rates, Spring 1976

Site	Date	a	b	r^2	Cumulative Infiltration 12 hour	24 hour
EB	4/18/76	.167	.825	.995	1.30	2.29
CSUB I	5/18/76	1.292	.532	.996	4.84	7.00
	6/3/76	.516	.695	1.000	2.90	4.70
CSUB II	5/5/76	.691	.624	.999	3.26	5.02
	6/4/76	.198	.676	.998	1.06	1.70
CSUB III	5/6/76	.706	.487	.997	2.37	3.32
	6/6/76	.282	.625	.998	1.34	2.06
CSUB IV	5/19/76	.887	.447	.985	2.70	3.67
	6/7/76	.187	.672	.996	.99	1.58
CSUB V	5/7/76	2.531	.313	.970	5.52	6.86
	6/8/76	.251	.694	.991	1.41	2.28
FKW I	4/16/76	3.234	.559	.995	12.96	19.09
	6/5/76	.533	.848	-	4.38	7.89
	6/18/76	.682	.750	-	4.39	7.39
	7/2/76	1.290	.150	-	1.87	2.08
	7/16/76	.434	.787	.999	3.07	5.29
FOR	4/14/76	3.449	.349	.986	8.22	10.47
	5/25/76	2.732	.412	.999	7.61	10.13
	6/17/76	2.432	.346	.999	5.75	7.30
	6/28/76	2.300	.407	.999	6.33	8.40
G-22	5/19/76	.346	.883	.999	3.10	5.72
	6/16/76	.092	1.026	1.000	1.18	2.40
	6/24/76	.203	.860	.992	1.73	3.13

Table 13. Measured intake rates, Spring 1976
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Site	Date		a	b	r^2	Cumulative Infiltration 12 hour	24 hour
G-23	5/17/76		.850	.697	.992	4.80	7.78
	6/17/76		.200	.831	.999	1.58	2.80
	6/26/76		.248	.846	1.000	2.03	3.65
G-24	5/19/76		.247	.956	1.000	2.66	5.15
	6/16/76		.162	.820	.999	1.24	2.19
	6/24/76		.155	.911	.998	1.49	2.81
G-25	5/17/76	64 rows	.500	.714	.976	2.94	4.83
	5/17/76	4 rows	.447	.700	.970	2.54	4.13
	6/17/76	33 rows	.170	.729	.990	1.04	1.73
	6/17/76	2 rows	.190	.702	1.000	1.09	1.77
	6/26/76	34 rows	.195	.781	.998	1.35	2.33
	6/26/76	2 rows	.374	.474	.995	1.22	1.69
GIE I	4/25/76		1.984	.456	.970	6.16	8.46
	5/16/76		.397	.739	.998	2.49	4.16
	6/9/76		.301	.781	-	2.10	3.60
	6/22/76		.229	.722	-	1.38	2.27
GIE II	4/22/76		.629	.743	.995	3.98	6.66
	5/18/76		.613	.743	.998	3.89	6.51
	6/9/76		.342	.714	-	2.02	3.31
	7/2/76		.199	.803	.999	1.46	2.55
LDS	5/22/76		2.219	.324	.919	4.96	6.21
LS I	4/28/76		.925	.368	.995	2.31	2.98
	6/14/76		.114	.730	.999	.70	1.16
	6/30/76		.046	1.011	.989	.56	1.14

Table 13. Measured intake rates, Spring 1976
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Site	Date	a	b	r^2	Cumulative Infiltration 12 hour	24 hour
LS II	5/7/76	3.119	.322	.968	6.94	8.61
	6/16/76	.321	.806	.986	2.38	4.16
	7/6/76	.260	.765	.978	1.74	2.95
STS	5/13/76	.206	.906	.998	1.95	3.65
	6/22/76	.201	.961	-	2.20	4.27

at most sites was nearly twice that of subsequent irrigations. Such a phenomena is probably realistic since several irrigators reported this observation. The reasons for such a drastic reduction in intake following the first irrigation are still under study, but probably relate to either winter freeze-thaw cycles or the common practice of deep plowing to cover crop residue. Regardless of the cause, the result is that the infiltration rate is high at the time long irrigations are applied for germination. As a result, a disproportionate percentage of deep percolation loss probably occurs during the first irrigation.

These data will be furnished to the Soil Conservation Service, USDA, for use in developing a method of designing more efficient furrow irrigation systems in the Grand Valley. One phenomena obvious from the data is that advance time shows significant variations from one irrigation to the next. These variations are not always a function of changes in stream size. There is therefore further indication that intake rates vary considerably from one irrigation to the next. This phenomena is perhaps most evident on the Mesa soils. Large changes in intake from one irrigation to another will make efficient surface irrigation design quite difficult, unless innovative methods for surface irrigation can be developed such that the irrigation system, rather than the soil, controls irrigation application.

Chemical quality of tailwater runoff will be discussed in a later section of this report.

Quantity and Quality of Measured Deep Percolation

Vacuum extractors were installed under 12 sites in 7 fields (S1-6 plus those shown in Table 9) for direct measurement of deep percolation losses. In spite of careful attention to site selection, two of the extractors were subjected to sufficiently high water tables that the data are suspect, as shown in Table 14. Four additional extractors had operational problems during part of the season sufficient to invalidate the data for those extractors.

Data from the operable extractors were used to calculate the leaching fraction at each site. Total irrigation application was calculated by adding measured deep percolation to ET estimated from lysimeter data. No value of leaching fraction was calculated from depth of percolate collected at site EB because this field was cropped to barley, for which no ET estimates were made. Leaching fractions calculated by this technique ranged from .03 to .14, with a mean value at all extractor sites of .08, considerably less than the 0.22 leaching fraction calculated for the same sites from the chloride profile technique. Table 15 compares the leaching fractions calculated by these two techniques and by three additional techniques to be discussed subsequently.

Leaching fraction was also calculated from the Cl^- concentration of the leachate collected in the extractors. The weighted mean chloride concentrations from vacuum extractors, shown in Table 16,

Table 14. Deep percolation measured from vacuum extractors and nonweighing lysimeters, 1975

		May cm	June cm	July cm	August cm	September cm	October cm	November cm	Total cm
EB	1	4.39	0.19	-	1.61	-	-		6.19
	2	1.61	0.14	1.87	0.77	-	-		4.82
	3	2.00	0.25	1.70	1.68	-	-		5.63
CSUB	1	-	-	0.30	5.13	3.84	-		9.27
	2	-	-	0.20	2.07	5.05	-		7.32
	3	-	-	-	0.22	0.27	-		0.49
G24	1	-	-	-	-	0.06	-		0.06[1/]
	2	-	0.47	2.31	1.41	-	-		4.19
	3	-	0.21	0.04	-	-	0.09		0.34[1/]
G25	1	-	0.17	0.03	0.02	-	-		0.22[1/]
	2	-	1.81	0.31	0.35	2.39	0.03		4.89
	3	-	0.78	0.12	0.06	-	-		0.96[1/]
LDS	1	-	-	2.78	0.55	0.11	0.02		3.46
	2	-	-	4.11	4.20	4.57	1.29		14.17[2/]
	3	-	-	2.64	2.62	1.89	-		7.15[2/]
LS	1	-		2.55	1.61	4.44	0.29		8.89
	2	-		1.96	0.26	-	-		2.25
	3	-		2.21	0.84	3.50	0.28		6.83
S1		0.60	-	1.09	0.72	0.27	0.15		2.83
S2		0.26	0.83	0.66	0.47	0.64	0.33		3.18
S3		0.06	1.72	1.84	1.45	1.94	1.69		8.71

Table 14. Deep percolation measured from vacuum extractors and nonweighing lysimeters, 1975
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	May cm	June cm	July cm	August cm	September cm	October cm	November cm	Total cm
S4	0.05	1.86	0.37	-	0.07	0.20		2.56
S5	-	0.09	2.14	1.38	1.01	0.80		5.40
S6	0.36	1.70	1.92	1.24	3.23	1.69		10.14
Non-Weighing Lysimeters								
S1	1.09	3.74	2.99	1.76	2.07	1.96	0.63	14.25
S2	0.31	0.69	1.67	1.44	2.29	2.39	0.62	9.41
S3	0.01	1.13	0.54	0.02	-	0.19	-	1.89[1/]
S4	0.07	0.04	0.15	0.01	0.88	2.19	0.61	3.95
S5	0.01	0.09	0.09	0.29	0.20	0.88	0.24	1.79
S6	0.03	0.01	0.03	0.28	2.59	0.01	-	2.96[1/]

[1/] Inoperative during all or part of season; disregard data.

[2/] May have been influenced by high water table; disregard data.

Table 15. Comparison of leaching fraction calculated by various techniques

Site	Cl^- Profile	Cl^- Vacuum Extractor	Water Volume Vacuum Extractor	Water Volume Non-Weighing Lysimeter	Water Balance
EB	0.26	0.08	-	-	-
CSUB	0.15	0.36	0.11	-	-
G24	0.34	0.19	0.05	-	0.05
G25	0.22	0.14	0.08	-	0.10
LDS	0.26	0.26	0.14	-	-
LS	0.26	0.10	0.10	-	-
S1	0.23	0.05	0.04	0.19	0.06
S2	0.14	0.09	0.04	0.12	0.09
S3	0.28	0.09	0.10	0.02*	0.18
S4	0.28	0.09	0.03	0.05	0.06
S5	0.18	0.25	0.07	0.02	0.13
S6	0.13	0.06	0.12	0.03*	0.17
MEAN LF	0.22	0.15	0.11	0.11	0.10
$S_{\bar{x}}$	0.02	0.03	0.03	0.03	0.02
MEAN (G&S Plots)	0.23	0.12	-	-	0.10
S_x	0.03	0.02	-	-	0.02

*Inoperable during part of the season; disregard results.

Table 16. Weighted mean chloride concentration of percolate collected in vacuum extractors

Site	Cl^-, meq/ℓ 1974	1975
EB	-	21.3
CSUB	-	5.0
G24	11.7	9.3
G25	18.0	15.0
LDS	-	6.7
LS	-	17.1
S1	35.3	31.0
S2	15.5	24.4
S3	17.4	23.3
S4	20.1	21.0
S5	-	7.2
S6	42.1	20.5

were divided into the weighted mean Cl^- concentration of total applied water, taken as 1.77 meq/l as in previous calculations for the Cl^- profile technique. Individual chemical analyses of these samples are shown in Table A-1 of the Appendix. Leaching fractions calculated by this method ranged from .05 to .36, with a mean of 0.15. As might be expected, this mean leaching fraction lies between the means calculated from extractor volume and from Cl^- profile analysis, since the accuracy of this calculation is effected by the same limitations as the Cl^- profile technique and the weighted Cl^- concentration is affected by errors in volumetric measurement by the vacuum extractors.

For the S1-6 sites, LF was also calculated from water collected in the non-weighing lysimeters, using the same water application calculated for the LF determinations from water collected in the vacuum extractors. Though the mean leaching fraction calculated by this method does not appear beyond reason, individual values do not necessarily follow the trend of either the intended percolation or the actual water application. As of this time, no explanation of the erratic results from the non-weighing lysimeters is apparent. These results are disregarded in subsequent discussion.

At the intensive study site (G24-25 and S1-6) both water application and runoff were measured for the entire 1975 season. These data, combined with changes in soil water storage and estimates of ET allowed calculation of the total water balance to evaluate deep percolation losses, as shown in the last column of Table 15. These calculations gave similar results to those from the vacuum extractors, and the mean calculated leaching fractions were not significantly different.

Because the Cl^- concentration from the vacuum extractors, the water volume collected by the vacuum extractors, and the water balance technique gave similar results at the intensive study site, and neither technique can be shown more accurate than the others, perhaps the best estimate of actual leaching is given by the mean of all three methods. This mean LF is 0.10, only 42% of the value calculated by the chloride profile technique at these same sites. The factors tending to increase apparent leaching fraction, as calculated by the chloride profile technique, such as high infiltration rates early in the season and approximately ten-fold change in irrigation water quality over the season, exist valley wide. Thus, it is reasonable to assume that this same correction can be applied to the Cl^- profile samples collected throughout the valley. The maximum estimated leaching fraction of 0.308 is reduced to 0.129, reducing the estimated average valley-wide annual leaching to 15.2 cm (6.0 inches) and the annual total deep percolation to 28,000 acre feet from the Grand Valley. These figures seem much more reasonable in the experience of the researchers involved, as it was observed to be very difficult to infiltrate a sufficient amount of irrigation water to replace the calculated depletion on the Ravola soils at the intensive study site.

Measurement of Evapotranspiration

Initial instrumentation at the intensive study site included an electronic weighing lysimeter under the center pivot sprinkler (plot S2). Because this lysimeter is irrigated lightly and frequently, it could be argued that ET measurements from this lysimeter are not representative of that from the typical Valley corn field. Thus, four additional lysimeters were installed during the winter of 1974-75 to check potential ET estimates as well as crop coefficient curves.

Potential ET was calculated using the technique of Kincaid and Heermann (1974). Calculated values are compared with measured ET from a well watered alfalfa crop to determine accuracy of the calculated potential. The alfalfa was harvested twice during the growing season thus greatly reducing the measured ET for a short period until regrowth provided full ground cover. Thus, measured values of ET before and after cutting were extrapolated through this post harvest period to adjust measured ET to that of a continuously growing alfalfa crop. Figure 10 shows the comparison of cumulative ET from the alfalfa lysimeter with cumulative estimated potential ET. During the period 6/14 through 10/8 the ET for the alfalfa lysimeter was 36.33 inches. Calculated potential ET during the same period was 28.54 inches, only 87.6% of measured potential. This difference suggests either errors in measurement of climatic data or in estimation of empirical coefficients of the energy balance equation. The pyranometer used for solar radiation measurements was checked against a recently calibrated Eppley pyranometer for a period of several days during late summer, 1975. The two instruments recorded total incoming radiation within 2% of one another, considered to be acceptable agreement.

As calibrated at both Kimberly, Idaho and Mitchell, Nebraska, the ARS computer scheduling model estimates net solar radiation, depending on maximum and minimum temperature, saturated vapor pressure, and solar position, at approximately 50 to 60% of total incoming shortwave radiation (the latter is more readily measured than net radiation, especially in remote locations). During the latter part of the 1975 growing season and in 1976, a Fritschen type net radiometer was installed over the alfalfa field to provide a calibration of this aspect of the scheduling program. Comparison of the two methods showed that mean net radiation in the Grand Valley is 80% of total solar, or 46% greater than calculated using the calibrations from Kimberly and Mitchell.

These results were also verified on the corn lysimeters. During the period 6/14 to 10/8 the G25 lysimeter measured 31.23 inches ET compared with a calculated ET of 19.4 inches, or 61% greater than calculated. Part of the explanation for this large difference may be due to the fact that the program reduces estimated ET as the soil dries following an irrigation, to compensate for reduced consumption as plant water stress increases. This aspect of the program is probably overly compensating for the soils of this area, perhaps due to the widespread occurrence of shallow water tables and the

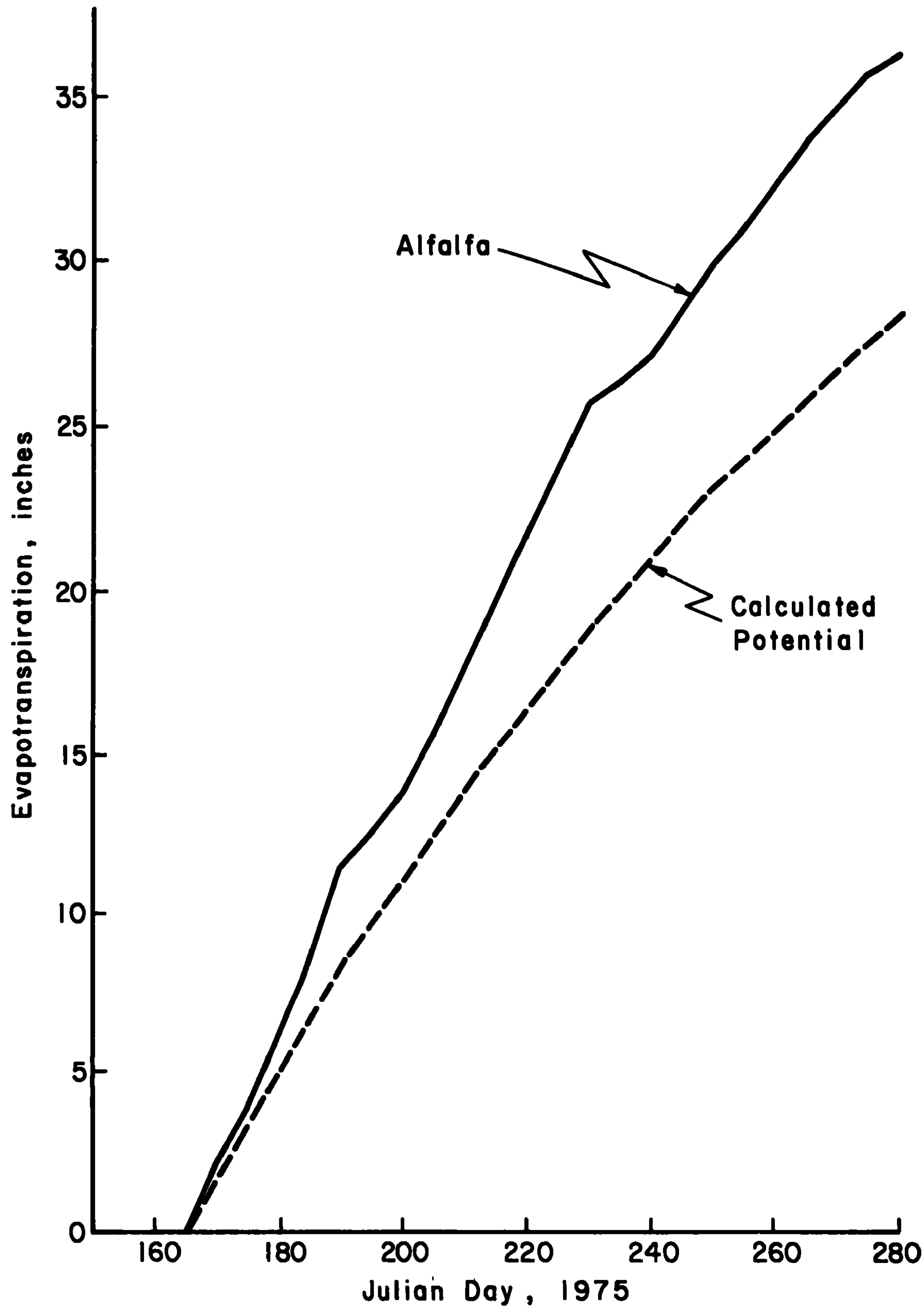

Figure 10. Comparison of estimated potential ET with measured ET from alfalfa

ability of the crop to use groundwater. It should also be pointed out that the G25 calculated ET was based on the actual irrigation timing and amount on plot G25. The lysimeter was kept well watered, and was not necessarily irrigated with the same depth or schedule as the remainder of the field.

During this same period, the S2 lysimeter measured 26.63 inches ET, or 18% greater than the calculated value. Early in the season, calculated ET was considerably higher than measured, probably due to overestimation of evaporation from the frequently wetted soil surface. From 7/1 through 10/8 measured and calculated ET's were 23.65 and 18.11 inches respectively, thus measured ET was 31% greater than calculated.

Figure 11 shows the crop coefficient curves calculated by various methods. First, from the ratio of alfalfa ET to calculated potential, it is apparent that the error in potential ET calculation is not constant throughout the season, but peaks in mid season. As expected, the crop coefficient curves calculated from estimated potential indicate higher crop use than possible with the available energy (i.e., the actual net available energy is greater than estimated by the scheduling program).

Crop coefficient curves calculated from potential ET as measured in the alfalfa are much more reasonable. Several points are worthy of mention, however. First, it appears that peak water use occurs later in the season than predicted by Kincaid and Heermann. Second, the curves indicate higher ET early in the season from the sprinkler irrigated corn than from the surface irrigated. During this period, plant cover is sparse and the crop is able to utilize only a portion of the net radiation energy for transpiration. Because the soil surface is considerably wetter under the frequent irrigation applied by the sprinkler, one would expect more evaporation from the soil at this stage in S2 than in G25, where irrigation is applied at about 14 day intervals. As full cover is reached, however, and the crop is able to utilize most of the net radiation energy for transpiration, the wetness of the soil surface is of little importance. Following full cover, in fact, it appears that the ET from the S2 plot is significantly less than from the gravity irrigated plot. The water balance for the sprinkler lysimeter is based upon the amount of water, in liquid phase, actually applied to the crop and soil surface (i.e., water that can be weighed by the lysimeter). It is obvious that part of the water pumped through the sprinkler heads evaporates before it hits the crop canopy, especially during periods when net radiation energy is high. From Figure 11, it is seen that peak measured ET from the sprinkler lysimeter is about 12% less than from the surface irrigation lysimeter. Earlier data collected at this location showed that during the afternoon in mid summer, about 16% of the pumped water evaporated before hitting the crop canopy. Many investigators consider this evaporation to be a loss of water. The current data, however, indicate that this airborne evaporation does in fact use part of

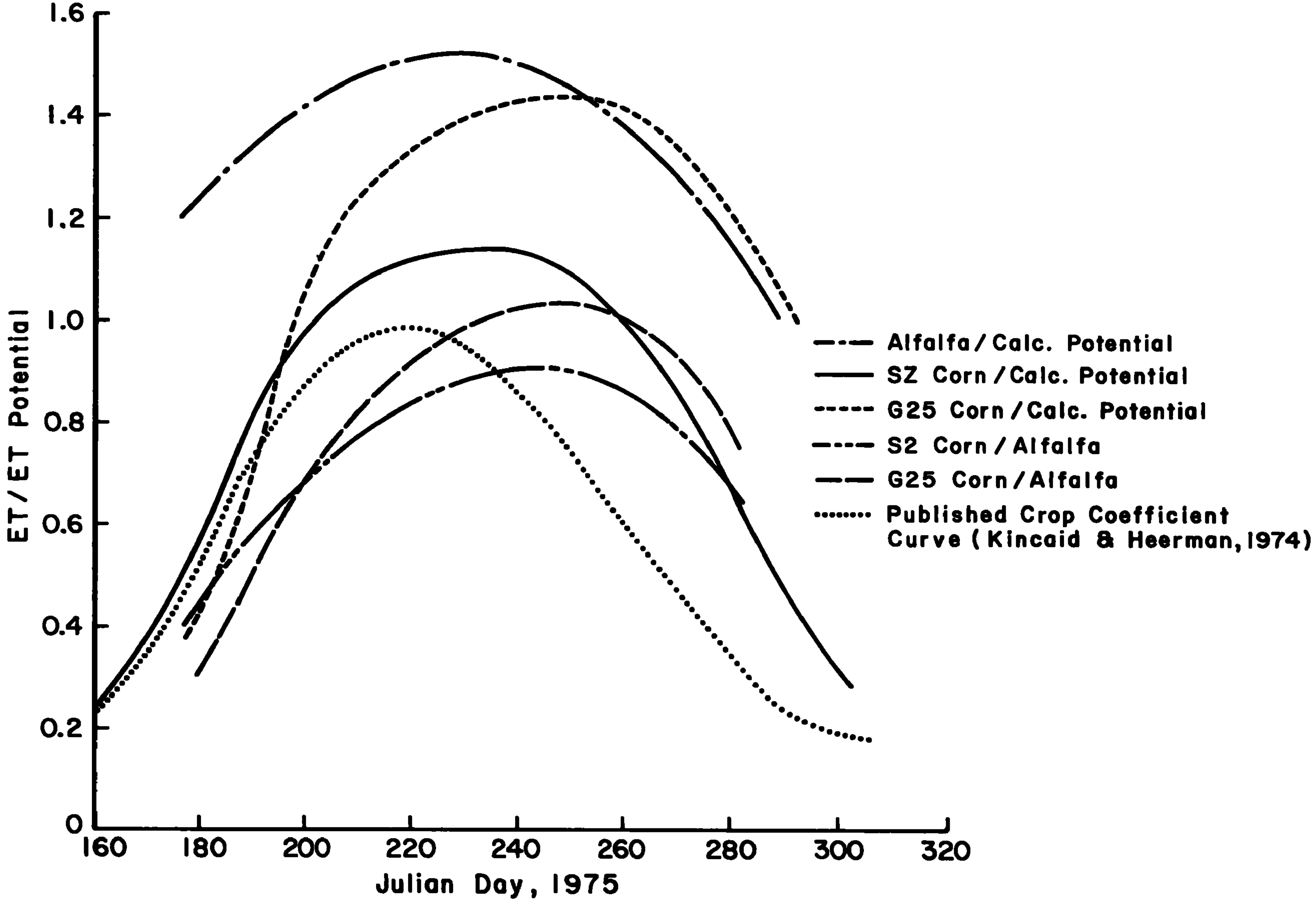

Figure 11. Ratio of evapotranspiration to potential ET as a function of time

the incoming energy (it must, of course) thus effectively reducing the transpiration through the plant by approximately the same amount as the airborne evaporation. Therefore, direct evaporation from a sprinkler system cannot be considered a loss of water nor a reduction in irrigation efficiency.

Two additional lysimeters were installed on the Colorado State University Experiment Station near Fruita. The first was installed under corn and operated from 6/14 through 10/8/75. During this period, measured ET was only 17.41 inches, only 55% of the ET measured on the G25 lysimeter under the same type irrigation. Corn plants on this CSUC lysimeter were observed to be stunted, indicating poor growing conditions; therefore these data were discounted as unrepresentative.

The second lysimeter was planted to sugarbeets, with considerable difficulty encountered in establishing a stand. The crop was finally established by transplanting on 7/12/75, and the lysimeter performed satisfactorily until 8/19. At that time, overirrigation of the adjacent field resulted in flooding of the readout well. Despite diking, excess water moving through the backfill material resulted in flooding the well at two subsequent irrigations, floating it out of the ground the last time (9/22/75) rendering the lysimeter useless. Total indicated ET during the period 7/12 through 9/22 was 20.59 inches compared with 23.02 inches for the G25 corn lysimeter and 24.65 inches measured potential. Thus the gross value of ET during this period is reasonable, but without much confidence. From final planting (7/12) to first flooding (8/19), total measured ET was 13.51 inches compared with 13.99 inches potential. These figures are felt to be reasonably reliable, but did not accomplish the original goal of verifying the crop coefficient curve for sugarbeets.

With the exception of the lysimeter that was flooded beyond use, all lysimeters are being operated during the 1976 growing season to strengthen ET estimating procedures.

Evaluation of Tailwater Runoff

Results of tailwater runoff measurements were briefly discussed in connection with Table 10, where runoff depths are tabulated for each irrigation measured. Table 17 summarizes the results of these studies. It is apparent from Table 17 that a considerable amount of tailwater runoff leaves the field, a fact easily verified by field visits during the irrigation season.

The relatively low infiltration rates and slow capillary movement of water in these soils necessitate long infiltration opportunity time to attain reasonable amounts of infiltration, especially in the early spring when the farmer must rely on irrigation to wet the seedbed for germination and emergence. Large amounts of runoff are also indicated by the ratio of advance time to total time of irrigation. The average irrigation time for the fields studied was

Table 17. Tailwater runoff from study sites in Grand Valley

Soil	No. Sites	No. Irrigations	Fraction of Runoff: Mean	Fraction of Runoff: Standard Deviation of Mean
Billings	2	16	.321	.052
Chipeta-Persayo[1/]	1	2	.593	.249
Fruita	2	15	.141	.034
Hinman	2	19	.255	.047
Mack	1	7	.319	.102
Ravola	9	58	.400	.028
Average all studies			.336	
Weighted mean			.363	

[1/] Not representative; uncropped area.

27.7 hours, while the average irrigation flow reached the bottom of the field in 6.6 hours. Such rapid advance contributes to a high degree of uniformity in infiltration.

The data of Table 17, though limited in statistical significance for some soils, shows that runoff percentage is not significantly different from the Billings, Chipeta-Persayo, Hinman and Mack soils. Differences in management from farm to farm and even from one irrigation to another are greater than soil differences. It does appear, however, that less runoff than average occurs from the Fruita soils, and more than average from the Ravola soils. Extensive data collected on Ravola soils give some idea of the reduction in runoff that can be achieved by careful water management. From the farmer irrigated sites, average tailwater runoff was 47.6 percent of total applied irrigation water. However, at the intensive study site, where net application was predetermined and application and runoff monitored during irrigation, average runoff was reduced to 31.8 percent, or one third less than on farmer irrigated sites. This reduction in runoff, however, was accomplished at the expense of a considerable amount of labor and expertise to monitor application during the course of an irrigation. Such a practice is certainly not feasible for the farmer operated system, and it is not likely that substantial reductions in tailwater runoff can be achieved on a valley-wide basis until innovative irrigation techniques, including automation and automatic water measurement can be developed.

Even though amounts of tailwater runoff are relatively large, the detrimental effects of salt loading from this runoff are not immediately obvious. During the 1975 irrigation season, water samples were collected periodically at the various study sites for both sediment and chemical analyses. The results of these analyses are shown in Table 18. Note that there is no statistical difference in electrical conductivity, chloride concentration, or nitrate concentration between the delivered irrigation water and tailwater runoff. Since the ions involved are quite water soluble, they are readily moved beneath the soil surface by the advancing irrigation front and are not subject to significant removal from the soil by surface runoff water.

Sediment concentration, however, is increased by a factor of approximately ten as water moves through the field. Thus, the average acre inch of runoff increases in sediment load by about 328 pounds. Based on an average crop ET estimate of 32 inches and the deep percolation and runoff estimates derived in this study, the 63 inches farm delivery and 8 inches precipitation reported by Skogerboe (1972) can be apportioned as shown in Table 19. Using these figures, the calculated sediment contribution is about 6560 pounds per acre or 190,000 tons total annually, assuming all tailwater runoff returns directly to the river. Such is not the case, however, as a portion of tailwater runoff is picked up downslope

Table 18. Chemical and sediment analysis of irrigation water, 1975

Site	Date	Inflow					Runoff				
		EC mmho/cm	Cl^- meq/l	NO_3^- meq/l	P ppm	Sediment g/l	EC mmho/cm	Cl^- meq/l	NO_3^- meq/l	P ppm	Sediment g/l
CHR	6/26	.610	.880	.083		0.23	.630	.940	.077		0.18
	7/24	.769	1.57	.124	.032	0.22	.768	1.72	.076	.029	0.20
	8/29				.001	0.36				.060	0.16
CSUB	6/19	.357	.574	.123	.006	0.07	.394	.666	.197	.590	0.34
	7/23	.557	1.46	.041		0.20	.535	1.28	.035	.080	
	8/19	.831	2.66	.226		0.05	.852	2.32	.130	.090	
CSUW	6/19	.461	.942	.105	.003	0.18	.471	.932	.101	.006	0.11
EB	8/29	.908	3.59	.309		0.03	.860	3.60	.150	.146	0.81
FKW I	6/19	.583	.808	.075	.003	0.14	.589	.833	.140	.034	0.96
FKW II	8/1					0.20					0.38
	8/20	1.24	3.61	.080		0.07	1.24	3.59	.105		0.14
	9/2					0.01					0.05
	9/3	1.26	4.19	.150	.007	0.01	1.25	4.25	.120	.051	0.08
G22	9/11					0.12					0.13
G24	9/11										
G25	6/13	.442	.832	.068	.002	0.25	.546	.930	.150	.258	20.5
	8/27	.934	3.72	.287		0.10	.937	3.68	.309		2.44
HTM	6/3	.519	1.26	.093		0.27	.535	1.38	.115		1.83
	6/30	.410	.736	.062	.097	0.14	.440	.756	.086	.073	0.28
	7/31	.634	1.84	.064		0.08	.643	2.08	2.96		0.54
LDS	7/28		1.81	.109	.025	.001	-	-	-	-	-
	8/20	.905	3.54	.142		0.11	-	-	-	-	-

Table 18. Chemical and sediment analysis of irrigation water, 1975
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Site	Date	Inflow					Runoff				
		EC *mmho/cm*	Cl^- *meq/l*	NO_3^- *meq/l*	P *ppm*	Sediment *g/l*	EC *mmho/cm*	Cl^- *meq/l*	NO_3^- *meq/l*	P *ppm*	Sediment *g/l*
LS	6/3	.487	1.12	.130		0.39	.515	1.11	.153		0.79
	7/2	.450	.728	.124	.005	0.28	.530	.972	.209	.240	2.91
	7/23	.553	2.04	.031		0.40	.631	1.46	.061		0.16
	8/6	.708	1.96	.065	.008	0.22	.744	2.00	.075	.244	5.86
	8/26	.895	2.96	.242	.023		1.01	3.35	.207	.321	
	8/27	.860	3.48	.180	.014	0.12	.910	3.39	.160	.206	1.77
RTG II	6/11	.436	.702	.090	.004	0.20	.466	.712	.093	.059	0.51
RTG III	7/30	.696	2.04	.061		0.04	.794	2.25	.053		1.02
	8/19	.977	3.63	.098		0.08	1.09	3.87	.076		1.18
	9/5					0.02					0.06
S1-6	8/23	.830	3.60	.115	.007	0.00	1.02	4.60	.150	.141	1.82
STS I	6/12	.469	.812	.150	.001	0.36	.457	.666	.133	.163	3.25
	7/23	.509	1.31	.032		0.24	.562	1.23	.041		5.92
STS II	9/3	.940	4.04	.140	.013	0.12	.960	4.15	.150	.098	0.56
STS III	9/1					0.07					0.83
MEAN		.723	2.14	.118	.016	0.15	.780	2.28	.204	.146	1.60
$S_{\bar{x}}$		.044	.217	.012	.006	0.01	.045	.236	.087	.026	.497

for reuse in lower lying areas. This sediment yield amounts to 0.019 inch erosion annually, or 52 years to erode 1 inch of soil.

Table 19. Estimated average on farm annual water balance, Grand Valley

Precipitation	8.3 inches
12 month ET	34.4
Runoff	20.0
Deep percolation	5.1
Delivery seepage and spillage	11.2
Total water delivery	71.0 inches

Because the phosphorous complex equilibrates with soil minerals, phosphorous transport is usually associated with sediment transport. Mean P concentration of the tailwater runoff increased nine fold over that of the applied irrigation water. Based on the same runoff figures previously cited, phosphorous picked up in the tailwater amounts to about 0.9 pounds per acre annually.

In general, sediment concentration in tailwater runoff tends to decrease with time, during an irrigation as shown in Table 20. Thus, later increments of runoff contribute less sediment, and undoubtedly less phosphorous, to the river than does the initial runoff.

Thus, from chemical analyses, one can conclude that only sediment load or P concentration are definitely increased by the occurrence of tailwater runoff. (Note: Consideration of pesticide concentration in the runoff was not included in this investigation). Even these two parameters are not perfectly reliable indicators of runoff, as individual measurements occurred in which each was decreased as water moved through the field.

Lateral and Canal Seepage Losses

The total groundwater contribution in the Grand Valley is comprised of deep percolation beneath irrigated fields, exchange of water between open drains and the aquifer, and seepage from the unlined conveyance system. Underflow from the surrounding desert is a possible source of natural contribution. Several investigators have evaluated canal and lateral seepage in the valley during the past two decades or so. Robinson (1955) evaluated seepage from the central portions of the Grand Valley Canal system. Skogerboe and Walker (1972) studied seepage from several major canals and laterals in the eastern part of the valley, and Solomonson and Frazier (1958) evaluated lateral seepage. With little published information on canal seepage available for the western portions of the valley, ARS

Table 20. Sediment concentration as a function of runoff time

Site	Date	Time	Inflow	Runoff
			------*g/liter*-----	
RTG III	8/19/75	1130	.04	-
		1135	-	2.33*
		1158	-	0.93
		1300	.03	-
		1305	-	1.19
		1400	-	0.74
		1500	.16	-
		1505	-	0.72
G22	9/11/75	1500	.12	0.26*
		1930	-	0.08
	9/12/75	1400	-	0.06
G24	9/11/75	1515	.12	-
		1530	-	1.82*
		1930	-	2.84
	9/12/75	1400	-	2.03

*Indicates first runoff water.

Table 21. Results of seepage studies on major canals, Grand Valley

Canal	Length of canal *mi.*	Seepage rate *ft/day*	Average wetted perimeter *ft*	Q *cfs/mi.*	Source of Data
Government Highline (eastern valley)	55	.25	57.0	.87	Skogerboe & Walker (1972)
Government Highline (20rd to Little Salt Wash)	55	.32	47.7	.94	USDA-ARS, 1974
Government Highline (Adobe Wash to Little Salt Wash)	55	.36	47.7	.96	USDA-ARS, 1974
Price Ditch	12	.13	13.7	.11	Skogerboe, et al (1972)
Stub Ditch	12	.15	11.6	.11	Skogerboe, et al (1972)
Redlands Power	12	.40	14.8	.36	Skogerboe, et al (1972)
Grand Valley System (Mesa Co. Ditch)	110	.14	11.9	.10	Skogerboe, et al (1972)
(Central reach, GVC)		.30		1.0	Robinson (1955)

conducted ponding tests on the Government Highline Canal following the 1974 growing season. Table 21 summarizes the results of various investigations on the major canals. The mean seepage rate, weighted by canal lengths reported by Skogerboe and Walker (1972) is 0.6 ft^3/sec/mile. Using their reported figure of 237 miles of main canals results in a total seepage estimate of 142.2 cfs. These canals are operational approximately 200 days annually, resulting in an estimated 56,900 acre feet of seepage.

Whether or not seepage from canals contributes to the salt load in the Colorado River depends on whether and how it moves toward the River. If, however, all the estimated seepage water reaches the river at the salinity level of the gravel aquifer at the Bethel corner well (23 and H Roads), this seepage would contribute 770,000 tons of salt per year to the Colorado River, i.e., about the total salt load of the entire valley.

Further seepage occurs in distribution laterals after release from the main canals. Solomonson and Frazier estimated lateral seepage losses of .02 cfs per mile. Skogerboe and Walker (1972) measured seepage losses on nine laterals below the Price, Grand Valley, and Mesa County canals and found an average seepage loss of .32 cfs/mile. Near the end of the 1975 irrigation season, three flumes were set in lateral 35 for seepage measurements (see Table 22). Results reported show greater seepage than from ponding tests. However, the flumes used are expected to have a measurement error in the order of $\pm$ .05 cfs at the flow rates encountered. Following the 1975 irrigation season and again prior to the 1976 season, ARS evaluated seepage from three laterals below the Government Highline Canal, with the results shown in Table 22. Weighted mean seepage from ARS ponding tests following the irrigation season was 0.12 cfs per mile. Combining these data with those of previous investigators results in a mean estimate of 0.25 cfs per mile of lateral. Assuming that the total length of laterals is twice the length of major canals, (total lateral length below GHC in 5.63 mile reach from Little Salt to Big Salt Wash is 15.42 miles, or 2.75 times length of main canal) the total annual lateral seepage estimate is 47,600 acre feet per year, almost as much as from the canals themselves.

Since previous tests had been conducted in the fall, following irrigation, for logistical reasons, ARS assumed that the high fall water tables and possible sealing from sediment may give unrepresentatively low seepage rates. During the spring of 1976 ponding tests were conducted in two of the laterals tested earlier, numbers 30 and 35, as shown in Table 22. Seepage rates measured in these spring tests were 225% of the rates measured the previous fall. Undoubtedly, low spring water tables increase the seepage gradient from many reaches of the main canals as well as laterals, especially where the water table rises during the season to intersect the canal. Thus, actual annual canal seepage is likely to be larger than estimated.

Table 22. Lateral seepage losses below GHC, 1975-1976

PONDING TESTS

Lateral No.	Pond No.	Test Date	Pond Length	Top Width	Depth	Slope	Wetted Perimenter	Water Surface Drop	Seepage Rates	
			ft	*ft*	*ft*	*ft/ft*	*ft*	*ft/da*	*cfs/mile*	*$ft^3/ft^2/da$*
30	1	10/29-31/75	600	5.3	1.5	.0012	6.8	.48	.16	.37
	2		600	4.0	1.2	.0030	5.2	.48	.12	.37
	3		520	5.1	1.4	.0017	6.5	.46	.14	.36
	4		538	5.7	1.9	.0010	7.6	.50	.17	.38
	avg		565	5.0	1.5	.0017	6.5		.15	.37
30	1	3/25-28/76	100	6.1	1.4	-	7.7	.90	.34	.72
	3		100	5.3	.6	-	6.2	1.25	.40	1.07
	avg		100	5.7	1.0	-	7.0		.37	.90
33 (main)	1	10/28-31/75	720	4.3	1.2	.0015	5.5	.46	.12	.36
	2		137	4.4	1.4	.0020	5.8	.74	.20	.56
	3		350	4.8	1.6	.0010	6.4	.68	.20	.51
	4		300	3.0	0.8	.0015	3.8	.82	.15	.65
	avg		377	4.1	1.2	.0015	5.4		.17	.52
35	1	10/30-31/75	268	5.0	1.4	.0040	6.4	.43	.13	.34
	2		1100	5.2	0.8	.0006	6.0	.17	.05	.15
	3		1000	5.1	0.9	.0005	6.0	.21	.07	.18
	avg		789	5.1	1.0	.0017	6.1		.08	.22
35	2	3/24-26/76	100	4.9	1.4	-	6.3	.46	.14	.36
	3		100	5.1	1.2	-	6.4	.35	.11	.28
	avg		100	5.0	1.3	-	6.4		.12	.32

Table 22. Lateral seepage losses below GHC, 1975-1976
Page 2

INFLOW-OUTFLOW TESTS, LATERAL 35

Date	Time	Flume No. 1		Flume No. 2		Flume No. 3		Seepage Rate*	
		Depth *ft*	Flow Rate *cfs*	Depth *ft*	Flow Rate *cfs*	Depth *ft*	Flow Rate *cfs*	Section 1 (1.0 mi) *cfs/mi*	Section 2 (0.9 mi) *cfs/mi*
10/24	1530	.72	2.20	.69	2.05			.15	
10/26	1530	.59	1.59	.55	1.41			.18	
10/27	1630	.54	1.37	.50	1.20			.17	
10/28	0900	.99	3.73	.93	3.37	.92	3.31	.36	.07

Ground Water and Return Flow

From previous discussions, it is apparent that canal and lateral seepage, deep percolation, precipitation, and tailwater runoff do not contribute directly a large part of the pollutant (salt) loading of the Colorado River in the Grand Valley. Investigation of water levels in open pits adjacent to the river at several locations suggests that groundwater gradients are always toward the river. Thus direct recharge from the river is not expected to be significant. Of major importance, however, is the route and mode of water movement after its loss from the irrigation system and before it enters the river.

To give further insight into groundwater movement toward the river, in 1974, Edmund Schneider, a graduate student in the Department of Earth Resources, Colorado State University, commenced a study of surficial geology in the Grand Junction-Fruita area as part of the current ARS studies. His objectives were 1) to delineate exposures of Mancos Shale and local stream and Colorado River alluvium; 2) to define the subsurface topography of the Mancos Shale erosion surface where it underlies alluvium; 3) to determine the degree of weathering, general permeability, and the extent and nature of surface and subsurface water seepage in the weathered zone of the Mancos Shale; and 4) to determine the areal extent and thickness of the Colorado River-deposited cobble aquifer which underlies the southern portion of the study area. The geologic complexity of the area is perhaps best described in Schneider's words:

> "The area of investigation encompasses 150 square miles of the Grand Junction - Fruita area of the Grand Valley of the Colorado River in west-central Colorado. Bedrock consists entirely of marine Upper Cretaceous Mancos Shale which is locally covered by Quaternary alluvium. The saline Mancos Shale and alluvium have a profound influence on groundwater salinity and drainage problems in the Grand Valley.
>
> The relatively broad form of the Grand Valley developed during several cycles of erosion associated with Late Pliocene or Early Pleistocene uplifting of the Uncompahgre Plateau.
>
> A portion of the study area which extends three miles north and parallel to the Colorado River includes up to 70 feet of tributary alluvium overlying 15 to 20 feet of Colorado River bedload materials (local cobble aquifer) deposited on eroded Mancos Shale. The northern edge of the buried Colorado River deposits is bounded by a dissected Mancos Shale terrace. The terrace was dissected by tributary streams originating

in the Book Cliffs to the north which downcut to the level of the Colorado River channel at its northernmost position. The bedload materials were deposited as the Colorado River migrated laterally southward prior to the establishment of its modern position.

In response to the lateral shift of the Colorado River, the southward flowing tributaries became aggraded upstream to re-establish equilibrium grade. As a result, the south side of the valley was ultimately filled with tributary alluvium.

Construction of a bedrock contour map revealed that a major buried tributary valley is present in the Little Salt Wash-Adobe Wash area near Fruita. The presence of this valley provides a basis for the development of a model for the subsurface configuration of the Grand Valley. In addition, it provides a means of explaining how the cobble aquifer system is hydrologically and stratigraphically connected with the tributary alluvium north of the cobble aquifer.

Drill holes constructed in the study area revealed that Colorado River alluvium could be distinguished from tributary alluvium on the basis of gravel composition. River gravels are derived from Precambrian granitic, gneissic, and Tertiary basaltic rocks whereas tributary gravels are entirely derived from sandstone and siltstone members of the Upper Cretaceous Mesaverde Group and Tertiary Wasatch and Green River Formations.

Drill holes augered into the Mancos Shale revealed that there is an artesian water-bearing zone on the weathered-shale and fresh-shale interface from 5 to 15 feet below the weathered-shale surface. Recharge is by seepage along exposed shale reaches of unlined canals. Even though the shale is vertically impermeable, recharge occurs along laterally interconnected bedding planes and joints. The shale water system is too meager to be considered a significant aquifer, but salts leached from the Mancos contribute to groundwater salinity. Analysis of shale water revealed that it was saturated with respect to calcite and gypsum.

Monitoring of water levels in drill holes showed that the artesian shale water dried up after the canals were turned out in October. In comparison, the water table in the alluvium dropped

> only slightly during the winter months. Recharge to the unconfined water system is primarily from irrigation waters as recharge from local intermittent washes is negligible. Therefore, the lack of a significant drop in the water table was attributed to poor drainage controlled by the predominance of thick sequences of clay and silt deposits interbedded with thin, discontinuous, and poorly sorted sand and gravel lenses. This apparent poor drainage significantly reduces the effectiveness of groundwater flow as a means of flushing out dissolved solids, and is the cause of local high water table conditions."

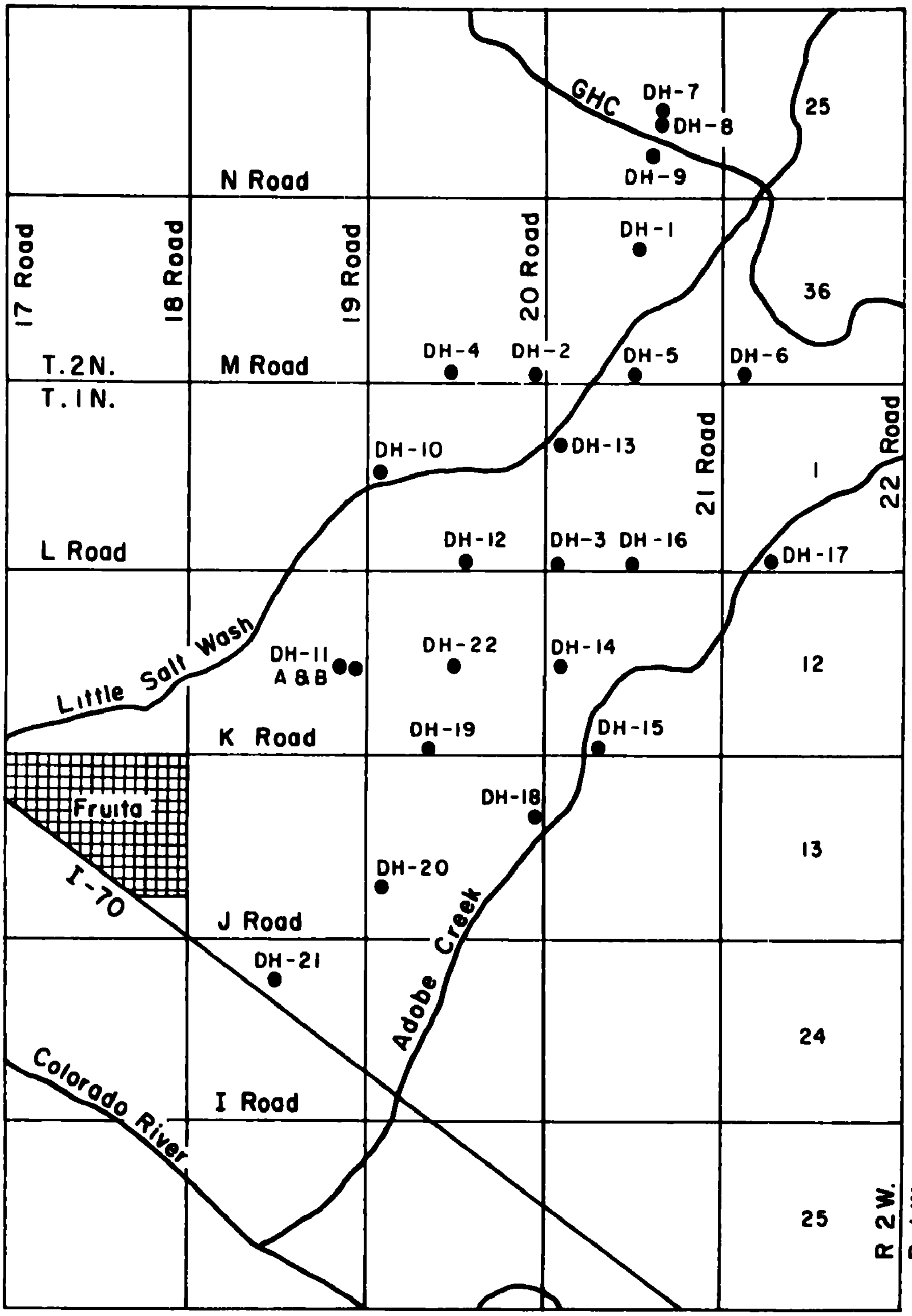
Schneider drilled 23 observation wells throughout the area between Adobe Creek and Little Salt Wash (see Figure 12). Water levels in these wells are being measured regularly, and samples being taken for chemical analyses. Table A2 in the Appendix shows the water level fluctuations measured from summer 1974 through spring 1976. Figure 13 illustrates that water table response, even at some distance from the canal, is quite rapid once the canal is filled (April 14). Considering Schneider's analysis of the upper Mancos shale, this rapid response is apparently due in part to seepage through the bedding planes and joints within the shale.

Chemical analyses of samples collected from these wells are given in Table A3 of the Appendix. Changes in electrical conductivity (EC) with time in some wells (1, 19H, 21, 22H) indicates a seasonal dilution by less saline water, particularly during summer and fall as seepage water migrates through the aquifer. Other wells (11A, 11B, 12, 13, 15) show little change in EC with time. The fact that those wells showing fluctuating EC are not located in any particular portion of the study area illustrates the complexity of the primary transport paths for return flow.

Wells 20 and 21 lie clearly in the area of the cobble aquifer, but water from these wells was unsaturated with $CaSO_4$ (gypsum) at all six sampling dates. Previously, water from all wells in the cobble aquifer was saturated with $CaSO_4$ in areas east of the locations of wells 20 and 21.

Three other wells (1, 3, and 16) above the cobble aquifer always showed water samples unsaturated with $CaSO_4$. Some other wells (11A, 17, 18, 19, and 22) had water saturated with $CaSO_4$ for part of the sampling dates. For example, well 22H was unsaturated with $CaSO_4$ on 10/12/75 and 11/18/75 but the water was saturated or near saturation with $CaSO_4$ at other sampling dates. This well is located near the Grand Valley Canal, but above it.

Although individual wells showed rather large changes in EC with time, the mean EC at the various sampling dates were not significantly different from the overall mean of 5.72 mmhos/cm. This might suggest that, although the path of water movement has considerable influence on water quality in the groundwater, the



DH-1 ● Drill Hole Location

Figure 12. Drill hole locations. Little Salt Wash-Adobe Wash areas.

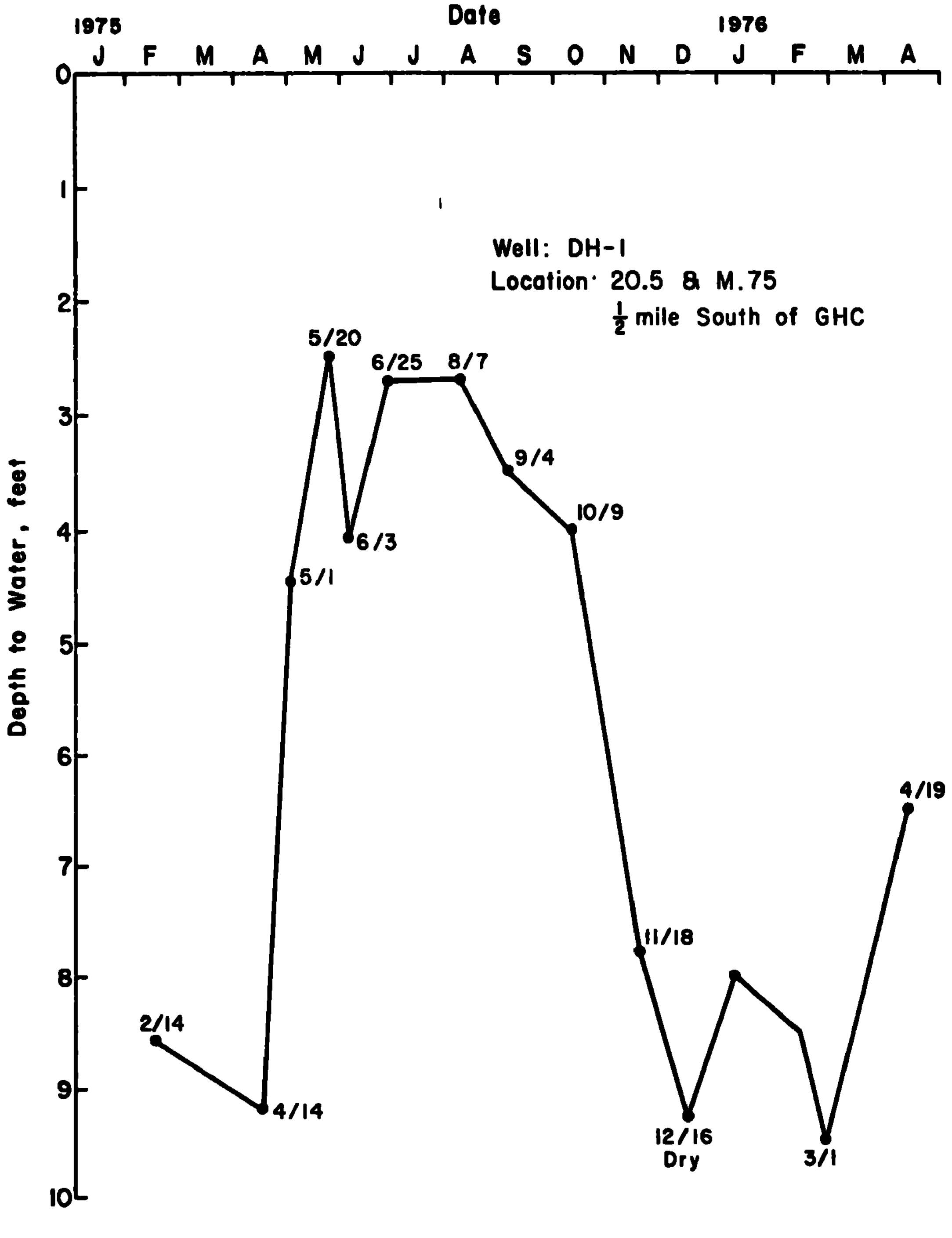


Figure 13. Response of water level in observation well to seepage

amount of movement (as interpreted from date of sampling) does not. One could carry such an inference further to say that, since the quality of return flow doesn't change in inverse proportion to the rate of return flow, i.e., seepage and deep percolation, then the salt load to the river is proportional to volume of deep percolation and seepage rather than their quality as they leave the root zone or canal, respectively. Thus, management of pollutants in return flow depends primarily on control of water rather than chemical modification.

The natural washes in the valley run generally perpendicular to the canal system and the river and frequently cut both the gravel aquifer in the lower reaches and the fractured shale in the upper reaches. As a result, most washes flow year around and provide an important route of transport of salt to the river. Flumes installed in nine washes were used to measure base flows into the washes during the winter months. Periodic samples were collected at each station for chemical analyses. Discharge measurements and calculated salt loads at four sampling periods for each measuring station are shown in Table 23 (complete chemical analyses are given in Table A4 of the Appendix). In each case, the flow increases at successive downstream positions, indicating that base flow (soil and aquifer drainage) occurs throughout the irrigated area. During this winter period, no significant trend in flow rates could be detected. Because of the rapid response of groundwater levels to canal diversion, the subsurface drainage removed by these washes is undoubtedly larger during the irrigation season than indicated by these measurements.

No significant trend was observed in EC of the drainage water during this period. This is further indication that whatever water percolates to the groundwater reaches an approximate equilibrium concentration, regardless of the rate of water movement (i.e. the exposure time). However, Little Salt, Persigo and Indian washes showed statistically significant trends of increased concentration from the Government Highline Canal toward the river. This indicates pickup of more saline water (i.e. water from the cobble aquifer) in the lower reaches of these washes. These results correspond to results of seepage meter tests conducted in selected reaches of these three washes. During December 1973, a thermal infrared scanner was used to detect warm spots in the cold surface waters of all the Grand Valley washes, which were indicative of concentrated inflows of warmer groundwater. Subsequently, meters capable of measuring either positive or negative seepage rates and of collecting a sample of influent water were installed at the concentrated inflow locations indicated by thermal IR imagery. Typical chemical analyses of water collected are shown in Table 24. Each of these three washes had locations of concentrated inflow of water having considerably higher salinity than the adjacent surface flows.

An attempt was made to extrapolate the drain flow and salt loading measurements to an annual salt loading contribution by the

Table 23. Drain flow and salt measurements, winter 1975-1976

	12/17/75			1/7/76			1/22/76			2/5/76		
	Q, cfs	EC, mmhos	S.L. tons/day	Q, cfs	EC, mmhos	S.L. tons/day	Q, cfs	EC, mmhos	S.L. tons/day	Q, cfs	EC, mmhos	S.L. tons/day
Little Salt Wash												
1	0.34	3.17	2.70	0.25	3.47	2.17	0.22	3.04	1.67	0.21	3.00	1.58
2	0.96	3.93	9.44	0.66	4.16	6.87	0.62	3.87	6.00	0.47	3.66	4.30
3	2.03	4.08	20.72	1.42	3.44	12.22	1.21	4.36	13.20	1.40	4.06	14.22
4	4.95	4.65	57.58	3.50	4.80	42.03	3.80	4.53	43.06	4.00	4.36	43.63
Adobe Wash												
1	0.20	4.58	2.29	0.17	4.79	2.04	0.12	4.73	1.42	0.13	4.58	1.49
2	1.53	4.37	16.73	0.95	4.60	10.93	1.00	4.34	10.86	0.84	4.27	8.97
3	2.80	4.65	32.57	2.28	4.87	27.78	2.28	4.46	25.44	2.32	4.58	26.58
Hunter Wash												
1	0.25	4.70	2.94	0.07	5.12	0.90	0.07	4.81	0.84	0.01	3.27	0.08
2	2.55	4.63	29.54	1.90	4.79	22.77	1.85	4.78	22.12	1.80	4.56	20.53
3	-	4.72	-	4.10	5.03	51.59	3.75	4.85	45.50	3.90	4.71	45.95
Persigo Wash												
1	0.47	4.45	5.23	0.35	4.46	3.90	0.36	4.36	3.93	0.35	4.23	3.70
2	3.15	4.80	37.82	2.80	4.99	34.95	2.70	5.00	33.77	2.80	4.66	32.64
3	7.60	5.37	102.10	4.12	5.51	56.79	3.93	5.42	53.29	4.11	5.36	55.11
Leach Creek	2.52	4.55	28.68	2.22	4.56	25.32	2.01	4.32	21.72	1.81	4.30	19.47
Indian Wash												
1	0.23	4.79	2.76	0.14	4.64	1.63	0.11	4.99	1.37	0.11	4.37	1.20
3	1.79	6.09	27.27	1.61	5.88	23.68	(1.60)	5.92	(23.70)	1.74	5.73	24.94
Lewis Wash	0.25	4.58	2.86	0.23	4.48	2.58	0.19	4.43	2.11	0.18	4.35	1.96
Big Salt Wash West												
1	0.55	3.50	4.82	0.45	3.69	4.15	0.53	3.43	4.55	0.65	3.77	6.13
2	3.90	3.94	38.44	2.40	4.02	24.14	2.18	3.84	20.94	2.35	3.56	20.93
Big Salt Wash East												
1	0.40	3.70	3.70	0.30	4.77	3.58	0.31	4.46	3.46	0.25	4.37	2.73
2	2.50	3.74	23.39	1.65	3.93	16.22	2.60	4.02	26.15	1.45	3.89	14.11

Table 24. Water composition from adjacent sites in Persigo, Little Salt, and Indian Wash drains, Grand Junction, 1975

Drain and Location	Site	EC mmhos/cm	me/l Ca	Mg	Na	Cl	SO_4	NO_3	HCO_3	pH	$pCaSO_4$	PCO_2, matm.
Persigo-5	stream	1.73	8.38	4.77	5.65	3.22	11.60	.21	3.60	8.02	5.35	1.56
	meter	3.50	15.57	15.71	15.65	4.08	38.32	.26	4.44	7.82	4.85	2.64
Persigo-7	stream	1.72	8.08	4.77	5.65	3.10	14.42	.17	3.50	7.61	5.29	3.91
	meter	1.93	9.58	5.43	6.30	3.40	14.62	.14	4.04	7.21	5.24	11.08
Little Salt-7	stream	1.10	4.09	2.14	4.13	3.44	7.06	.13	3.20	7.89	5.73	2.02
	meter	1.26	5.24	2.55	4.56	2.88	7.56	.14	3.40	7.41	5.63	6.36
Little Salt-8	stream	1.03	3.94	1.89	4.13	2.80	6.05	.11	3.20	7.54	5.83	4.58
	meter	1.50	6.99	3.29	5.00	3.02	8.07	.13	4.00	7.31	5.44	9.14
G. V. Canal	Indian W.	0.37	1.84	1.63	.98	.61	1.26	.11	2.10	7.83	6.60	1.75
Indian Wash	G. V. Canal	1.83	9.67	6.52	4.78	2.26	14.87	.22	3.36	7.82	5.22	2.27
Indian Wash	spring	2.50	13.13	8.16	9.13	2.98	22.81	.27	4.00	7.55	5.01	4.76

washes. The average total daily winter salt load of the nine washes reported in Table 23 (assuming an EC of 1 mmho/cm equals total dissolved solids of 928 ppm) is 285.9 tons per day. Assuming that this rate and concentration of base flow is continuous throughout the year, the total salt load removed through these washes is 104,000 tons per year. There are at least 18 major natural washes in the Grand Valley, plus numerous open artifical drains. Therefore one might assume that the total winter base flow rate is about twice that measured in this study. If groundwater flow during the irrigation season (because of higher groundwater levels) is substantially greater than during the winter months, these drains may be the mode of tranport for practically all of the calculated salt load contributed by the Grand Valley. More complete studies of total drain discharge are currently being conducted by the U. S. Bureau of Reclamation and U. S. Geological Survey.

It was originally intended to attempt to employ various types of tracers to determine specific flow paths of the various components of the groundwater. However, after evaluation of the geologic study, observation well data, results of canal seepage tests, and the drain investigation, the project leaders concluded that the expense of adequate test equipment and boring would be prohibitive, the results would be very site specific, and the probability of conclusive results at any selected site was small. Therefore, tracer studies were not given further consideration.

SECTION VIII

APPLICABILITY OF METHODS TO SIMILAR AREAS

One of the overall objectives of this study was for the researchers involved to make a subjective appraisal of the techniques employed in this study and evaluate their applicability to similar evaluations in other areas. Many aspects of the study utilized proven methods such as neutron attenuation instruments for soil moisture measurements, ponding tests for determining canal and lateral seepage rates, and standardized laboratory methods for chemical analyses. Orifices, critical depth flumes and commercial propellor meters were used for measurement of surface components of the water balance. Perhaps a word of caution is in order regarding use of flumes for estimating deep percolation losses. Unless calibrated in place, one can expect an average accuracy of about ± 5% from critical depth flumes. Where large amounts of runoff occur, and ET estimates are subject to errors on the order of ± 10%, the gross measurement error, which is normally lumped into the deep percolation term, can be quite large relative to the actual deep percolation. As an example, if 63 inches irrigation water is applied, one third is tailwater runoff, and ET is estimated at 32 inches, measurement errors expected may result in estimated deep percolation loss ranging from 2.5 to 17.4 inches, or a calculated leaching fraction ranging from 0.07 to .38. Of course, the probability of all errors being in the direction to produce these extreme estimates is small, but the example illustrates that calculations by this technique are not exact.

The hydraulic lysimeters used in this study are of a type previously described by Hanks and Shawcroft (1965) with an improved readout system to allow maintaining the readout underground for better control of temperature influences. These lysimeters have a realistic resolution of at least 0.2 mm (.008 inches) of ET. Although resolution is not as good as the best electronic weighing systems, these lysimeters are quite economical, costing 10% or less the price for an electronic device, and requiring no electrical power for operation. The lysimeters used in this study were fabricated of exterior grade plywood with an asphaltic sealant applied. This appears to be satisfactory for about two season's use, although marine grade plywood is recommended to reduce warping. Lysimeters anticipated to be used for longer periods should be fabricated of impervious materials, such as steel, or if properly braced, fiberglass.

The vacuum extractors serve two purposes, i.e. to measure the amount of percolating water and to provide a sample for chemical analysis. With proper pretreatment of the ceramic tubes (Duke and Haise, 1973), it is felt that the chemical aspects of extractor samples are representative of the mobile soil water. One must be aware, however, of the possible chemical changes that occur after sample collection, particularly carbonate reactions effected by reduced pressures in the collection system.

Accuracy of the extractors with respect to rate of percolation is much less clearcut. Interception accuracy depends on the maintenance of a zero horizontal gradient at the top of the metal trough. Because of indeterminable head loss in the vicinity of the candles (which is also a function of the rate of percolation), applied vacuum must be greater than the ambient soil suction. By the nature of the soil physics and physical properties pertinent, coarse textured soils are many times more tolerant of errors in applied vacuum than are fine textured soils. The present researchers have had quite consistent results from these devices when installed in the clean, uniform Valentine sand, but their application in the clays and clay loams of the Grand Valley requires very careful measurement of soil water suction both inside and outside the metal trough. Obviously, the extractors are limited to operation within the range of soil water suction between saturation and the vapor pressure of a free water surface (about 0.8 atmosphere). Thus, the device cannot be expected to operate satisfactorily under non-irrigated lands in arid or semi-arid regions, nor when located very near to a water table or under conditions of very high percolation as might be encountered beneath a canal or groundwater recharge structure. It is particularly important that the device be installed by the "undisturbed" technique, described in Section V, in fine textured soils, soils with significant structural elements, for studies where chemical aspects are important, or where gravity irrigation techniques are used. Open trench installation will invariably disturb both the chemical and physical properties to the point that results may not be representative for many years, if ever. Because of the time and expense of installation and the constant attention required, the vacuum extractors are not suitable as a survey tool, but under the conditions described may prove useful in research situations.

The technique of using chloride concentration as a means of measuring water use by plants is a technique of long standing. It is frequently applied to pot and lysimeter studies where total effluent can be collected, usually with a water table or other constant water content at the bottom of the soil container. The application of this technique to field soils has been apparently successful in some areas, notably the desert southwest. In these areas, precipitation is quite insignificant compared with the high annual ET, irrigation (and presumably percolation) proceeds year around, although less frequently during the winter, infiltration is not influenced by winter freeze-thaw cycles, and we suspect that chloride concentration in the irrigation water changes rather gradually with time due to the mixing in the many reservoirs providing the typical water supply for these regions.

In the Grand Valley, however, precipitation, though low, approaches 25% of the annual ET, providing considerable dilution and flushing of accumulated soil salts. High initial infiltration rate, deep plowing and cracking of these expansive soils promotes deep percolation early in the growing season. Because the irrigation supply of the Grand Valley is from direct runoff, with no in-line storage, this early streamflow is primarily from snowmelt and is of very high quality. As snowmelt recedes and groundwater flow becomes the primary water source for the river, chloride concentration in the late summer will typically increase ten fold. These factors complicate leaching fraction calculations by the chloride technique considerably. Not only must many samples be analyzed to take into account the soil variability encountered, but one must also develop a history of precipitation, irrigation water quality, and even deep percolation to adequately apply the chloride profile technique for leaching fraction calculations. Such calculations are further complicated by high water tables, posing the probability of net upward flow of groundwater, and by extreme soil stratification, which may result in substantial lateral movement of soil water.

Thus, we have concluded that the chloride profile technique, though it may provide a relative measure of leaching and may be more accurate than conventional water balance techniques, is not directly applicable for leaching fraction calculation in the Grand Valley. One aspect of the results, however, must not be deemphasized. Each of the factors complicating the procedure tends to result in an overestimate of the leaching fraction. Thus, even if a shallow water table is present, the technique, with adequate numbers of samples, should give an upper limit to the expected leaching fraction.

The computer scheduling technique, and methods of calculating ET necessary for its application, has been used for more than a decade, but is still viewed with skepticism by some. Although average ET rates for a given crop at a particular time of year may be perfectly adequate scheduling information for the desert southwest where precipitation is negligible and climate varies little from year to year, most of the irrigated acreage in the western U. S. has sufficient precipitation and climatic variability that constant estimates of ET are not adequate for irrigation scheduling. The ARS Scheduling Program has proven quite successful in widely separated areas, and has been adopted, either directly or in modified form, by the Bureau of Reclamation and by numerous commercial farm consultants. Without a doubt, ET estimates by this procedure are much more accurate than the water measurement devices provided on the majority of western surface delivery sytems.

Although not treated in detail in the studies reported here, several tracer techniques are worthy of mention at this point. During early phases of the USBR study, we employed an airborne thermal infrared scanner to detect small differences in surface temperature of the flow in natural drains to pinpoint areas of concentrated groundwater inflow into the drains. This equipment is capable of detecting temperature differences on the order of 0.1°C and resulted in quite clear delineation of areas where warm groundwater enters the washes. The technique is widely used to detect seepage from impoundments and mixing of tributary flows in rivers.

Further tracer techniques originally envisioned for this study included introduction of tagged ions, uncommonly encountered halogens, fluorescent dyes and neutron activation analyses to detect the presence of artificially introduced non-radioactive ions. These techniques were discounted, not because of lack of confidence in the tracer technique, but because the complex geological characteristics would give very site specific results, with little chance of extrapolation to the valley as a whole. The one tracer discovered that seemed to have promise was the ratio of naturally occurring Ca^{+2} and Mg^{+2} ions in the water. Early analyses showed quite consistent Ca/Mg ratios of the order of 0.5 for water directly associated with river flow and about 2.0 in water known to have passed through soil materials. It was felt that this ratio, even though the concentrations varied widely, might readily identify whether a given sample of water had passed through the groundwater system or was strictly associated with surface flows. As studies were expanded to cover other areas of the valley, however, numerous inconsistencies between Ca^{+2} and Mg^{+2} ratios developed. Although these inconsistencies may well have resulted from local geologic conditions, the concept of Ca/Mg ratio as a tracer was eventually dropped.

SECTION IX

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SECTION X

APPENDIX

TABLE A1

WATER ANALYSES, NON-WEIGHING LYSIMETERS, S1-6, 1975

Plot	Date	EC mmhos/cm	me/1			Plot	Date	EC mmhos/cm	me/1		
			Cl	SO_4	NO_3				Cl	SO_4	NO_3
S-1	6/19	3.32	15.38	11.44	4.31	S-4	6/19	3.31	15.40	10.70	4.09
	7/7	3.48	14.60	8.09	4.11		7/7	3.67	16.00	9.38	3.58
	7/23	3.18	11.20	9.00	2.55		7/23	2.99	12.00	9.59	1.76
	7/18	3.01	8.71	10.37	2.96		8/18	2.51	12.75	10.80	1.40
	9/2	2.79	6.94	8.05	4.35		9/2	2.64	11.65	8.60	2.12
	9/9	2.80	6.50	9.09	5.33		9/23	2.73	12.00	10.10	.471
	9/23	2.62	5.49	10.02	2.95		10/30	2.65	11.70	10.20	.611
	10/30	2.60	6.89	11.14	2.63		11/18	2.67	11.25	9.75	.740
	11/18	2.83	8.38	10.17	2.42						
S-2	6/19	3.78	16.00	22.70	.513	S-5	6/19	3.32	15.50	10.00	3.66
	7/7	4.04	16.02	23.47	.439		7/7	3.62	16.05	14.00	4.20
	7/23	3.97	15.57	18.37	.476		7/23	3.13	11.07	11.34	1.52
	8/18	3.94	15.72	21.36	.312		8/18	2.82	10.50	12.35	.419
	9/2	3.93	15.13	20.10	.553		9/2	2.82	10.45	10.22	.530
	9/9	3.80	13.90	18.40	.525		9/9	2.70	10.30	14.00	.650
	9/23	3.66	13.15	18.50	.366		9/23	3.67	10.00	21.60	1.78
	10/30	3.46	12.30	18.22	.385		10/30	2.87	9.22	12.87	1.13
	11/18	3.53	11.84	18.12	.590		11/18	2.96	10.11	14.28	.613
S-3	6/19	6.08	26.40	43.80	3.02	S-6	6/19	3.50	15.20	10.70	2.84
	7/7	6.26	25.18	39.40	2.66		7/23	3.52	11.60	9.29	2.37
	7/23	3.94	14.37	17.13	2.12		8/25	3.37	11.80	12.80	5.85
	8/18	5.16	21.30	32.40	2.15		8/27	5.18	12.70	32.10	5.35
	9/2	3.25	9.91	10.80	2.52		9/2	5.14	11.90	35.20	8.11
	10/30	4.89	19.30	32.00	1.12		9/9	4.89	10.80	34.54	6.41
	11/18	3.28	12.00	14.60	.91		9/23	4.58	9.89	36.30	4.50
							10/30	3.81	9.48	29.70	3.71

Each date represents mean values of 1 to 5 sampling dates.
All chemical analyses reported in Table A1 were conducted at the U. S. Salinity Laboratory, Riverside, California.

WATER ANALYSES FROM VACUUM EXTRACTORS, 1975

Site	Date	EC, mmhos/cm			Cl, me/l			SO_4, me/l			NO_3, me/l		
		N*	M	S	N	M	S	N	M	S	N	M	S
CSUB	7/25	3.38	3.79		10.0	13.9		10.9	13.0		7.71	5.44	
	8/13	3.15			9.42			8.32			4.63		
	8/18	1.47	3.33		3.82	12.4		5.54	10.1		.564	4.04	
	8/26	1.27	1.82	2.82	3.48	5.57	8.84	3.80	6.71	10.1	.577	.832	5.02
	8/28	1.26	1.72		3.20	5.26		5.68	7.39		.580	.350	
	9/3	1.22	1.20	2.47	3.20	4.09	8.26	3.03	4.13	7.39	.220	.140	2.11
	9/12	1.45	1.26	2.85	2.56	3.50	8.36	8.41	9.09	9.66	.545	.198	2.89
	9/17	1.46	1.38		2.54	3.84		6.82	6.82		.270	.384	
	9/24	1.42	2.04		3.23	6.13		6.82	11.3		.325	.338	
	H_2O leached, cm	9.3	7.3	0.5									
LDS	7/17	2.25	2.21	1.32	7.68	6.42	1.33	7.87	7.62	2.83	2.31	.400	.200
	7/23		1.91	1.31		5.48	1.29		4.89	3.02		.457	.100
	7/25	2.12	1.87	1.42	6.44	3.02	1.07	8.86	7.29	4.25	1.42	2.72	.228
	8/13	1.92		1.21	5.48		.92	7.06		6.05	.236		.164
	8/18	1.87		.99	5.40		1.06	6.56		3.66	.271		.109
	8/26		1.76	1.45		3.01	1.97		3.41	2.85		.536	.315
	9/3		1.53	1.54		2.39	2.82		2.73	3.14		.130	.140
	9/12	1.96	1.61	1.59	5.26	2.20	2.88	9.09	7.73	6.82	.260	.070	.107
	9/16		1.62	1.45		2.70	1.92		6.82	6.82		.182	.166
	9/24		1.60			2.53			6.88			.126	
	10/2	1.65	1.65		4.22	2.14		6.25	4.55				
	H_2O leached, cm	3.5	14.2	7.2									

*N = north end of field (top)
M = middle
S = south

WATER ANALYSES FROM VACUUM EXTRACTORS, 1975

Site	Date	EC, mmhos/cm			Cl, me/l			SO_4, me/l			NO_3, me/l		
		N*	M	S	N	M	S	N	M	S	N	M	S
LS	7/8	4.30	9.85	3.15	11.4	82.7	10.1	21.4	51.1	16.7	3.58	4.91	1.58
	7/17	4.16	9.42	3.21	11.9	81.2	11.1	20.2	36.3	17.6	2.04	5.34	1.09
	7/28	4.20			10.3			29.2			2.09		
	7/30		9.48	3.04		79.1	9.82		44.0	15.6		--	1.14
	8/18	3.90	10.73	3.19	8.94	82.1	9.12	25.2	47.4	14.1	.852	6.68	1.29
	9/12	3.52		3.22	6.86		7.56	23.8		18.0	.820		.520
	9/16	3.05		3.18	5.12		5.88	21.6		19.8	.226		.237
	9/25	3.13		3.15	5.76		6.48	24.3		21.8	.116		.149
	10/2	3.40		3.29	5.32		6.96	27.2		22.6	.267		.354
	H_2O leached, cm	8.90	2.25	6.84									
EB	5/7	3.28	3.84	9.40	7.69	9.79	86.5	29.5	27.8	71.1	.888	3.56	1.73
	5/20	3.41	4.05	8.61	8.60	11.9	74.7	30.9	28.4	71.6	1.03	4.09	1.07
	5/30	3.67	4.16	8.50	11.5	13.2	71.8	33.0	27.4	65.8	.911	4.26	1.67
	6/5	3.52	4.24	8.72	8.53	13.2	71.0	30.1	27.4	56.0	.774	3.48	1.61
	6/12		4.30	8.45		14.2	70.5		31.6	69.4		3.99	2.12
	6/16	3.50	4.19	8.16	8.24	13.1	69.5	29.5	28.1	66.9	1.13	3.84	2.30
	7/3	3.65			8.18			28.4			.833		
	7/8		3.29	6.95		4.55	39.4		28.5	58.3		.940	.960
	7/18	3.26	3.38	7.06	5.64	4.04	39.1	19.8	30.6	57.8	2.31	.840	.710
	9/17	3.12	2.77	5.01	7.74	4.16	17.2	23.2	21.9	42.1	.336	1.10	.924
	9/24		2.96			5.27			23.9			1.16	
	H_2O leached, cm	6.2	4.8	5.6									

*N = north end of field (top)
M = middle
S = south

WATER ANALYSES, VACUUM EXTRACTORS, G-24 (middle) 2

Date	Volume	EC	Ca	Mg	Na	K	Σ^+	HCO_3	Cl	SO_4	NO_3	Σ^-	SAR	Ca/Mg	Cl Ratio
6-17-74	100	4.48	19.7	11.2	17.4	.2	48.6	7.8	23.8	12.3	3.8	47.8	4.4	1.8	.10
6-19-74	248	5.06	28.0	13.3	17.8	.7	59.8	11.5	19.1	18.4	9.6	58.6	3.9	2.1	.12
7-03-74	2098	5.20	28.0	12.3	17.6	.1	58.0	11.6	19.9	15.5	9.3	56.3	3.9	2.3	.12
10-03-74	45	2.21	11.0	4.2	8.9	.1	24.2	9.0	7.1	6.8	1.4	24.3	3.2	2.6	.33
10-17-74	225	4.98	28.2	11.7	18.5	.8	59.1	13.5	18.8	18.3	9.0	59.6	4.1	2.4	.12
6-02-75	250	3.13	15.6	7.6	13.5	.4	37.2	13.0	7.4	11.2	5.7	37.3	3.9	2.0	
6-16-75	414	2.95	13.9	7.6	12.4	.4	34.2	15.2	4.7	7.9	6.6	34.4	3.8	1.8	
6-19-75	353	2.95	14.4	7.7	11.4	.3	33.9	14.5	5.2	8.3	6.1	34.0	3.4	1.9	
6-26-75	78	2.88	15.6	8.1	11.9	.4	36.0	16.0	5.2	8.3	5.2	34.7	3.4	1.9	
7-10-75	2585	2.76	14.1	6.7	10.7	.4	31.8	16.1	4.4	6.7	4.7	31.9	3.3	2.1	
7-23-75	2765	2.59	13.8	9.1	10.2	.3	33.5	17.3	3.7	7.6	4.0	32.7	3.0	1.5	
8-05-75	3170	2.47	13.3	8.3	9.2	.3	31.1	18.5	3.3	6.6	2.6	31.1	2.8	1.6	
8-11-75	107	2.55	14.4	8.7	10.1	.4	33.6	20.2	3.6	7.1	2.7	33.6	3.0	1.6	

WATER ANALYSES, VACUUM EXTRACTORS, G-24 (S) 3

Date	Volume	EC	Ca	Mg	Na	K	Σ^+	HCO_3	Cl	SO_4	NO_3	Σ^-	SAR	Ca/Mg	Cl Ratio
6-17-74	98	1.28	6.5	3.9	3.8	.4	14.5	8.7	2.6	3.6	.2	14.6	1.7	1.7	.9
6-19-74	222	1.43	6.9	4.1	4.4	.02	15.5	8.4	3.4	3.1	.6	15.6	1.9	1.7	.7
6-27-74	483	1.35	6.1	4.0	4.7	.1	14.9	8.5	2.9	3.4	.3	15.2	2.1	1.5	.8
7-03-74	435	1.42	6.6	4.7	3.7	.03	15.1	8.9	2.9	3.2	.1	15.1	1.5	1.4	.8
7-10-74	205	1.66	9.2	5.6	4.3	.1	19.1	10.8	3.6	4.4	.3	19.2	1.6	1.6	.6
7-17-74	1530	1.75	8.9	5.6	4.5	.04	19.0	11.2	3.9	4.2	.5	19.8	1.7	1.6	.6
7-24-74	487	1.82	9.8	6.4	4.8	.04	21.1	11.8	4.3	4.0	.2	20.3	1.7	1.5	.5
7-31-74	145	1.92	10.8	6.2	5.4	.1	22.5	12.1	4.7	4.7	.4	21.9	1.8	1.7	.5
8-12-74	52	2.00	10.7	6.6	5.1	.1	22.5	12.2	5.1	5.5	.3	23.1	1.7	1.6	.5
6-02-75	85	2.89	16.9	9.2	8.7	.1	34.9	11.7	11.4	9.9	1.6	34.7	2.4	1.8	
6-16-75	415	3.39	18.5	10.4	8.8	.04	37.7	8.3	14.9	11.7	2.8	37.7	2.3	1.8	
7-10-75	106	3.41	20.1	9.0	8.9	.1	38.1	8.7	14.7	9.8	5.2	38.4	2.3	2.2	
10-20-75	200	2.12	9.0	5.2	7.2	.2	21.6	4.3	8.8	6.6	1.1	20.8	2.7	1.7	

WATER ANALYSES, VACUUM EXTRACTORS, G-25 (N) 1

Date	Volume	EC	Ca	Mg	Na	K	Σ^+	HCO_3	Cl	SO_4	NO_3	Σ^-	SAR	Ca/Mg	Cl Ratio
7-03-74	180	5.27	26.7	21.8	9.0	.1	57.6	5.1	35.1	12.6	3.4	56.3	1.8	1.2	.07
7-10-74	445	5.20	26.0	20.6	9.8	.1	56.4	9.9	32.2	9.4	5.0	56.5	2.0	1.3	.07
7-17-74	225	4.89	24.0	18.0	9.5	.1	51.6	6.1	31.4	9.3	5.0	51.7	2.1	1.3	.08
7-24-74	425	4.76	26.0	17.3	8.4	.1	51.8	6.8	29.6	10.8	4.9	52.1	1.8	1.5	.08
7-31-74	308	4.78	24.8	16.9	8.8	.1	50.6	6.6	27.9	10.3	4.9	49.7	1.9	1.5	.08
8-12-74	303	4.92	24.5	17.0	10.0	.1	51.6	6.9	28.3	11.2	5.5	51.9	2.2	1.4	.08
8-30-74	291	4.75	24.1	18.2	8.6	.1	51.0	7.4	26.3	9.3	8.2	51.2	1.9	1.3	.09
10-18-74	100	4.73	25.5	17.2	9.6	.1	52.4	7.1	26.5	12.1	8.0	53.7	2.1	1.5	.09
6-16-75	228	5.66	28.8	20.3	13.6	.1	62.8	4.9	24.3	14.2	18.3	61.6	2.7	1.4	
6-19-75	90	5.66	29.7	19.3	13.9	.1	63.0	4.0	23.1	14.9	19.6	61.6	2.8	1.5	
6-26-75	75	5.57	31.6	20.0	13.2	.2	64.9	3.5	22.9	17.3	19.6	63.2	2.6	1.6	
7-23-75	75	5.38	28.7	21.5	13.7	.1	64.0	4.1	23.0	14.9	20.0	61.9	2.7	1.3	
8-05-75	50	5.38	24.6	19.7	13.3	.2	57.5	3.6	24.8	13.6	15.3	57.2			

WATER ANALYSES, VACUUM EXTRACTORS, G-25 (middle) 2

Date	Volume	EC	Ca	Mg	Na	K	Σ^+	HCO_3	Cl	SO_4	NO_3	Σ^-	SAR	Ca/Mg	Cl Ratio
6-27-74	1076	4.25	19.4	7.2	18.4	.2	45.2	9.7	17.9	11.2	6.8	45.5	5.0	2.7	.13
7-03-74	503	4.15	18.5	7.5	17.1	.2	43.2	9.9	14.9	10.1	7.9	42.8	4.7	2.5	.16
7-10-74	280	4.34	20.3	8.9	19.4	.2	48.7	10.2	18.1	12.5	8.2	49.0	4.4	2.3	.13
7-17-74	402	4.41	20.6	8.4	17.6	.2	46.8	10.7	19.3	11.2	7.2	48.4	4.6	2.4	.12
7-24-74	276	4.45	21.6	8.6	18.2	.2	48.6	11.2	18.4	9.7	8.2	47.6	4.7	2.5	.13
7-31-74	180	4.54	22.5	9.4	18.0	.2	50.1	11.1	19.1	10.6	7.6	48.3	4.5	2.4	.12
8-12-74	4037	2.30	10.4	4.0	9.2	.1	23.7	7.6	6.9	6.7	3.6	24.8	3.4	2.6	.34
8-30-74	1425	2.28	10.6	4.2	10.2	.1	25.2	10.0	6.1	5.4	4.3	25.8	3.8	2.5	.38
9-18-74	150	1.89	9.0	3.5	8.3	.1	20.9	9.2	5.6	4.9	1.3	21.0	3.5	2.6	.42
9-24-74	85	1.83	8.7	3.3	7.7	.1	19.8	9.1	5.7	4.5	.8	20.1	3.1	2.6	.41
10-17-74	175	1.87	8.4	3.0	7.7	.1	19.2	9.4	5.5	3.5	.8	19.2	3.2	2.8	.42
6-16-75	3919	2.37	10.3	5.3	10.5	.1	26.2	10.9	6.3	4.7	4.0	26.0	3.7	1.9	
6-19-75	167	2.41	9.7	5.9	11.2	.1	27.0	9.9	6.6	5.1	4.9	26.5	4.0	1.6	
6-26-75	127	2.68	13.9	6.4	10.6	.2	31.0	11.5	6.7	6.2	5.4	29.8	3.3	2.2	
7-10-75	214	2.69	13.8	5.2	10.7	.1	29.9	14.4	6.0	3.8	5.8	30.0	3.5	2.6	
7-23-75	500	2.92	15.5	7.6	11.1	.1	34.2	16.8	6.1	4.9	6.6	34.3	3.3	2.0	
8-11-75	185	2.96	16.3	7.4	11.4	.2	35.2	16.6	6.0	5.1	6.6	34.3	3.3	2.2	
8-18-75	147	2.89	16.0	6.9	11.4	.2	34.5	16.7	5.6	5.0	5.8	33.2	3.4	2.3	

WATER ANALYSES, VACUUM EXTRACTORS, G-25 (middle) 2

Date	Volume	EC	Ca	Mg	Na	K	Σ^+	HCO_3	Cl	SO_4	NO_3	Σ^-	SAR	Ca/Mg	Cl Ratio
8-25-75	488	2.88	15.3	6.8	11.2	.2	33.5	15.8	5.2	5.1	7.5	33.6	3.4	2.2	
9-02-75	1374	2.35	12.8	6.0	9.1	.2	28.0	15.1	4.7	4.2	28.8	3.0	2.2		
9-09-75	120	2.61	14.1	6.5	10.3	.2	31.0	18.3	5.0	3.5	4.9	31.6	3.2	2.2	
9-15-75	3930	2.44	13.2	4.7	8.8	.3	28.0	16.1	5.0	4.7	2.9	28.7	2.9	2.3	
9-23-75	120	2.43	13.4	5.9	9.2	.1	28.7	16.2	5.0	5.0	3.2	29.4	3.0	2.3	
10-02-75	65	2.13	10.7	6.1	9.3	.1	26.3	14.1	5.1	5.1	2.6	26.9	3.2	1.8	

WATER ANALYSES, VACUUM EXTRACTORS, G-25 (S) 3

Date	Volume	EC	Ca	Mg	Na	K	Σ^+	HCO_3	Cl	SO_4	NO_3	Σ^-	SAR	Ca/Mg	Cl Ratio
6-17-74	713	2.94	15.3	7.7	7.9	.2	31.1	6.3	14.0	6.5	4.1	31.0	2.3	2.0	.17
6-19-74	158	3.13	16.5	7.5	9.2	.2	33.4	6.9	14.8	6.1	4.8	32.7	2.7	2.2	.16
7-03-74	486	3.33	16.8	8.5	8.7	.1	34.1	7.2	15.3	4.8	5.4	32.8	2.4	2.0	.15
7-17-74	662	3.15	16.3	7.5	8.8	.1	32.6	7.3	14.4	5.0	6.2	32.8	2.5	2.2	.16
7-24-74	518	3.10	16.4	6.9	8.1	.1	31.5	7.1	13.5	5.7	5.5	31.8	2.4	2.4	.17
7-31-74	388	3.12	16.3	7.9	8.3	.1	32.6	7.1	13.7	6.1	5.5	32.4	2.4	2.1	.17
8-12-74	121	3.05	15.7	7.8	8.3	.1	31.9	7.1	12.8	7.7	5.5	33.1	2.4	2.1	.18
8-30-74	62	3.01	15.3	7.3	7.7	.1	30.4	7.5	12.6	5.2	6.7	31.9	2.3	2.1	.19
6-02-75	75	3.19	17.7	8.2	9.7	.1	35.7	8.0	13.8	7.7	6.2	35.6	2.7	2.2	
6-05-75	58	4.32	23.5	12.2	12.0	.1	47.8	6.5	17.2	9.2	14.2	47.1	2.8	1.9	
6-16-75	1449	4.87	28.5	13.1	14.6	.1	56.3	6.3	16.2	9.9	23.7	56.2	3.2	2.2	
6-19-75	125	4.89	26.5	13.2	15.2	.1	55.0	6.3	15.6	10.0	23.7	55.6	3.4	2.0	
6-26-75	114	4.88	29.9	14.1	14.5	.1	58.6	6.7	15.4	11.1	23.7	57.0	3.1	2.1	
7-23-75	280	4.79	26.8	14.8	14.7	.1	56.4	8.0	14.6	9.6	21.9	54.2	3.2	1.8	
8-05-75	135	4.46	23.0	14.0	15.2	.1	52.3	7.4	13.7	7.9	24.6	53.5			

WATER ANALYSES, VACUUM EXTRACTORS, S-1

Date	Volume	EC	Ca	Mg	Na	K	Σ^+	HCO_3	Cl	SO_4	NO_3	Σ^-	SAR	Ca/Mg	Cl Ratio
7-31-73	1235	1.91	7.3	6.6	6.9	.1	20.9	10.6	8.6	1.8	.3	21.3	2.6	1.1	.27
7-09-74	297	4.70	21.8	10.3	19.2	.2	51.4	8.1	28.0	6.8	6.7	49.7	4.8	2.1	.08
7-17-74	205	4.87	22.8	9.8	18.3	.2	51.1	9.7	28.6	5.7	7.8	51.9	4.5	2.3	.08
7-24-74	178	4.95	23.7	9.7	18.5	.2	52.1	10.6	27.7	6.3	7.9	52.4	4.5	2.4	.08
7-31-74	149	5.18	25.2	10.0	19.2	.2	54.7	10.1	29.9	7.2	7.3	54.4	4.6	2.5	.08
8-07-74	86	5.23	22.8	10.5	19.9	.2	53.4	6.6	31.4	7.4	7.8	53.4	4.9	2.2	.08
8-15-74	38	5.46	21.2	11.8	23.0	.4	56.4	4.6	33.6	8.3	10.4	56.9	5.7	1.8	.07
8-23-74	40	6.07	23.5	14.2	27.3	.3	65.3	4.0	39.8	8.5	12.7	65.0	6.3	1.7	.06
10-16-74	440	7.74	42.2	17.6	24.1	.2	84.1	10.7	45.6	13.8	15.7	85.9	4.4	2.4	.05
10-25-74	170	8.16	47.8	19.3	27.2	.3	94.5	9.6	52.0	13.6	22.1	97.3	4.7	2.5	.04
11-01-74	380	6.13	36.4	14.3	21.9	.1	72.6	9.4	31.8	17.3	15.5	74.0	4.3	2.5	.07
5-29-75	1400	7.61	46.3	19.4	24.3	.2	90.3	9.6	44.5	14.7	21.2	90.0	4.2	2.4	
7-01-75	90	10.90	62.9	28.6	38.9	.3	130.7	6.7	67.2	21.5	34.7	130.1	5.8	2.2	
7-08-75	307	8.21	50.2	18.4	30.3	.3	99.2	8.6	41.8	15.6	30.1	96.1	5.2	2.7	
7-14-75	700	7.24	45.0	15.7	25.4	.2	86.3	10.1	33.3	17.4	24.88	85.6	4.6	2.9	
7-18-75	400	6.97	42.8	18.4	25.3	.2	86.8	10.5	30.9	16.1	28.7	86.3	4.6	2.3	

WATER ANALYSES, VACUUM EXTRACTORS, S-1

Date	Volume	EC	Ca	Mg	Na	K	Σ^+	HCO_3	Cl	SO_4	NO_3	Σ^-	SAR	Ca/Mg	Cl Ratio
7-28-75	1030	6.63	40.5	19.2	23.5	.2	83.4	12.4	29.0	17.1	21.9	80.3	4.3	2.1	
8-05-75	550	6.24	37.0	17.0	22.2	.2	76.3	12.8	26.2	17.9	17.4	74.3	4.3	2.2	
8-11-75	400	5.84	34.1	16.4	23.6	.2	74.2	12.6	24.0	17.5	16.6	70.7	4.7	2.1	
8-18-75	420	5.56	32.4	14.5	21.5	.2	68.5	13.5	20.6	17.0	17.4	68.4	4.4	2.2	
8-25-75	300	5.56	31.1	14.0	23.3	.2	68.6	15.8	19.5	16.3	17.8	69.4	4.9	2.2	
9-02-75	270	5.32	29.5	13.2	21.8	.2	64.7	16.7	18.1	15.5	15.4	65.6	4.7	2.2	
9-08-75	180	5.27	28.0	13.1	23.0	.2	64.0	17.2	18.9	14.6	13.3	64.1	5.0	2.1	
9-15-75	70	5.48	28.8	14.0	22.3	.2	65.2	15.6	19.2	16.5	16.8	68.1	4.8	2.1	
9-22-75	100	4.98	25.2	13.8	21.4	.2	61.1	6.4	18.4	19.4	16.8	61.0	4.8	1.9	
9-29-75	10*	4.94	14.6	16.8	29.1	.5	61.0	3.7	25.1	22.1	10.1*	*	7.4	.9	
10-07-75	340	5.04	26.5	12.9	22.8	.2	62.4	17.1	18.8	14.0	12.4	62.4	5.1	2.1	

*Insufficient sample

WATER ANALYSES, VACUUM EXTRACTORS, S-2

Date	Volume	EC	Ca	Mg	Na	K	Σ^+	HCO_3	Cl	SO_4	NO_3	Σ^-	SAR	Ca/Mg	Cl Ratio
7-31-73	765	3.60	17.6	8.0	14.4	1.0	41.0	11.4	13.8	13.9	1.9	41.0	4.0	2.2	.17
8-07-73	505	3.96	26.4	9.1	13.6	1.1	50.2	15.2	10.4	21.2	2.4	49.2	3.2	2.9	.23
8-14-73	1175	4.04	27.4	10.9	11.9	.7	51.0	15.7	10.3	23.2	2.2	51.4	2.7	2.5	.23
8-24-73	1770		32.2	13.2	16.3			16.4	11.6	29.9	2.6	60.6	3.4	2.4	.20
8-31-73	2930		26.4	12.2	14.1	1.5	54.2	17.1	10.4	25.4	1.6	54.5	3.2	2.2	.22
9-20-73	260	4.43	30.4	12.4	14.1	1.1	58.1	17.4	11.2	26.7	1.9	57.3	3.0	2.4	.21
11-30-73	2735	3.67	13.8	13.2	14.0	.9	41.8	4.7	12.6	19.2	3.5	40.0	3.8	1.1	.19
12-17-73	510	4.76	32.6	13.8	15.4	.8	62.3	13.8	14.4	30.0	4.5	63.3	3.2	2.4	.16
4-27-74		4.98	32.8	14.2	15.6	.8	63.4	13.7	15.1	30.5	3.4	62.6	3.2	2.3	.16
6-19-74	1820	5.08	33.1	14.5	14.9	.9	63.3	11.4	17.0	30.8	4.3	63.6	3.1	2.3	.14
7-09-74	359	5.16	33.3	15.3	16.7	.9	66.2	10.9	17.7	30.1	5.0	63.8	3.4	2.2	.13
7-17-74	27	5.27	27.7	15.9	18.2	1.0	62.8	4.7	20.5	32.0	6.4	63.6	3.9	1.7	.11
7-24-74	28	5.38	28.0	16.7	19.0	1.2	64.9	4.6	20.8	37.6	3.6	66.4	4.0	1.7	.11
8-15-74	2590	3.13	14.1	9.6	12.1	.8	36.6	5.4	10.0	17.0	3.6	36.0	3.5	1.4	.24
8-23-74	530	3.72	15.8	12.6	13.8	.9	43.0	3.3	12.4	20.6	5.0	41.3	3.7	1.2	.19
9-30-74	316	4.86	19.1	17.0	19.6	1.1	56.8	3.3	17.4	29.9	6.5	57.1	4.6	1.2	.13
10-05-74	800	4.71	20.1	16.6	18.5	.9	56.0	3.1	17.1	28.7	5.0	53.9	4.3	1.2	.14
10-16-74	1440	4.80	21.9	17.9	19.0	.8	59.7	2.5	19.2	34.6	4.8	61.1	4.3	1.2	.12

WATER ANALYSES, VACUUM EXTRACTORS, S-2

Date	Volume	EC	Ca	Mg	Na	K	Σ^+	HCO_3	Cl	$SO_4^=$	NO_3	Σ^-	SAR	Ca/Mg	Cl Ratio
10-25-74	500	4.84	23.4	16.6	18.1	.9	59.0	2.3	20.9	29.2	5.1	57.4	4.0	1.4	.11
11-01-74	360	4.83	22.4	14.9	18.5	.7	56.4	4.2	20.8	27.0	5.3	57.2	4.3	1.5	.11
5-29-75	600	4.88	24.0	16.7	19.1	.8	60.6	3.8	22.8	32.7	3.8	63.1	4.2	1.4	
6-03-75	149	5.00	24.6	17.3	20.1	.8	63.0	4.4	22.8	33.8	3.8	64.8	4.4	1.4	
6-05-75	1200	4.90	23.3	16.9	19.8	.8	60.8	3.4	23.6	32.1	3.4	62.4	4.4	1.4	
6-16-75	350	5.15	21.4	18.2	22.1	.7	62.4	3.1	25.5	32.5	.1	61.2	5.0	1.2	
6-24-75	220	5.30	22.3	19.6	22.4	.9	65.2	2.5	26.9	32.5	3.3	65.2	4.9	1.1	
7-01-75	80	5.64	24.2	17.5	26.0	1.0	68.7	2.5	27.9	34.4	3.9	68.7	5.7	1.4	
7-08-75	208	5.23	23.1	16.0	22.7	.9	62.7	2.7	26.1	30.6	4.4	63.7	5.1	1.4	
7-14-75	250	5.00	21.6	15.2	21.7	.9	59.4	2.8	25.2	29.6	4.2	61.8	5.1	1.4	
7-18-75	250	5.02	21.2	15.2	21.9	.9	59.1	2.7	25.2	28.9	4.2	61.1	5.1	1.4	
7-28-75	740	4.86	20.1	20.9	20.7	.9	62.6	2.6	24.1	31.0	4.0	61.7	4.6	1.0	
8-05-75	410	4.84	19.8	20.8	21.6	.9	63.0	2.8	24.8	31.0	3.7	62.3	4.8	1.0	
8-11-75	250	4.89	20.0	20.1	22.2	.9	63.1	2.5	24.2	30.8	3.7	61.2	5.0	1.0	
8-18-75	270	4.97	19.8	19.1	22.1	.9	61.9	2.6	23.9	32.5	4.2	63.1	5.0	1.0	
8-25-75	170	5.15	19.1	19.0	23.6	.9	62.6	3.0	24.3	31.7	5.6	64.7	5.4	1.0	
9-02-75	460	5.11	18.8	18.9	23.6	.8	62.2	3.3	24.2	29.4	5.6	62.5	5.4	1.0	
9-08-75	430	5.02	18.6	18.9	23.0	.9	61.4	3.0	24.9	28.9	4.2	61.0	5.3	1.0	

WATER ANALYSES, VACUUM EXTRACTORS, S-2

Date	Volume	EC	Ca	Mg	Na	K	Σ^+	HCO_3	Cl	SO_4	NO_3	Σ^-	SAR	Ca/Mg	Cl Ratio
9-15-75	300	5.16	19.1	18.7	23.2	.9	61.9	2.7	24.4	32.1	3.6	62.8	5.3	1.0	
9-22-75	250	5.20	20.8	18.4	23.4	.8	63.3	2.8	24.2	33.3	3.4	63.7	5.3	1.1	
9-29-75	45	5.27	21.4	20.0	22.9	.9	65.2	4.5	21.6	33.7	4.6	64.5	5.0	1.1	
10-07-75	760	5.14	19.6	20.0	22.7	.9	63.2	2.5	24.9	33.9	3.8	65.2	5.1	1.0	
10-22-75	290	5.20	21.0	19.6	21.7	.8	63.1	2.9	26.3	32.0	1.1	62.4	4.8	1.1	

WATER ANALYSES, VACUUM EXTRACTORS, S-3

Date	Volume	EC	Ca	Mg	Na	K	Σ^+	HCO_3	Cl	SO_4	NO_3	Σ^-	SAR	Ca/Mg	Cl Ratio
7-31-73	370	6.17	21.0	13.0	32.2	.6	66.8	13.8	30.5	17.1	3.6	65.0	7.8	1.6	.08
8-07-73	320	6.22	20.3	13.9	39.5	1.4	75.1	14.2	30.5	29.7	3.8	78.2	9.5	1.5	.08
8-14-73	785	6.28	22.1	13.3	36.5	1.3	73.3	13.9	29.7	28.6	3.5	75.8	8.7	1.7	.08
8-24-73	3010		26.0	15.0	43.5			16.1	30.4	30.6	3.1	80.2		1.7	.08
8-31-73	685		17.8	14.8	40.8	1.9	75.3	21.5	25.8	26.8	2.2	76.3		1.2	.09
9-11-73	1190	6.87	24.8	14.8	47.4	1.3	88.3	24.9	26.3	33.5	3.4	88.2	11.0	1.7	.09
9-20-73	425	7.11	24.5	16.3	50.8	1.3	92.8	25.5	27.2	33.0	3.5	89.2	11.0	1.5	.09
11-30-73	853	6.00	13.9	12.6	42.7	1.0	70.1	15.6	23.6	25.9	5.0	70.1	12.0	1.1	.10
12-17-73	390	6.25	17.8	12.5	45.5	.8	76.6	20.0	23.9	25.6	6.2	75.8	12.0	1.4	.10
4-27-74		5.63	7.6	9.3	42.4	.9	60.1	12.2	20.3	22.9	6.7	62.0	15.0	.8	.12
6-05-74	870	5.59	13.2	8.3	41.9	.6	63.9	14.4	19.3	21.3	7.4	62.3	13.0	1.6	.12
10-05-74	480	5.59	13.0	8.5	43.4	1.0	65.9	19.2	18.1	19.8	9.0	66.1	13.0	1.5	.13
10-16-74	77	5.67	10.9	10.8	40.3	1.0	62.4	12.9	21.9	17.3	10.0	62.1	12.0	1.0	.11
11-01-74	1840	5.24	13.3	8.2	37.9	.8	60.2	19.8	16.1	15.0	10.4	61.3	12.0	1.6	.14
11-15-74	1550	4.96	7.3	8.8	40.9	.8	57.9	13.4	17.4	15.5	10.8	57.1	14.0	.8	.13
5-29-75	150	5.47	12.3	9.2	42.9	.9	65.3	17.5	19.1	18.1	9.2	64.0	13.0	1.3	
6-03-75	184	5.25	8.6	10.7	41.9	.9	62.1	13.9	19.0	17.0	11.4	61.2	13.0	.8	
6-16-75	3040	5.26	4.6	9.5	43.1	.8	58.1	11.3	19.4	16.9	11.3	58.9	16.0	.5	

WATER ANALYSES, VACUUM EXTRACTORS, S-3

Date	Volume	EC	Ca	Mg	Na	K	Σ^+	HCO_3	Cl	SO_4	NO_3	Σ^-	SAR	Ca/Mg	Cl Ratio
6-24-75	780	5.59	5.4	9.8	46.7	.9	62.8	12.1	21.1	18.0	9.3	60.6	17.0	.5	
7-08-75	325	6.89	11.9	13.7	54.4	1.1	81.1	14.1	28.3	21.2	17.0	80.6	15.0	.9	
7-14-75	540	6.98	14.3	13.2	54.2	1.1	82.8	13.5	28.1	21.6	17.8	81.0	15.0	1.1	
7-18-75	1180	6.86	13.0	12.9	53.6	1.0	80.6	11.4	28.3	21.6	18.7	80.0	15.0	1.0	
7-28-75	2120	6.82	12.5	18.1	52.3	1.0	83.9	10.1	28.6	26.9	16.6	82.2	13.0	.7	
8-05-75	2150	6.54	9.8	17.5	51.8	1.3	80.4	8.2	28.4	24.7	17.4	78.6			
8-11-75	630	6.60	11.8	17.0	52.3	1.0	82.1	9.6	27.4	28.8	15.8	81.7	14.0	.7	
8-18-75	1180	6.62	12.8	16.1	53.0	1.0	82.9	12.2	27.0	29.4	11.5	80.0	14.0	.8	
8-25-75	1380	6.54	10.5	15.8	56.3	1.0	83.5	12.6	25.6	29.4	13.3	80.8	16.0	.7	
9-02-75	1480	6.28	9.8	15.6	50.6	1.0	77.0	12.5	25.8	28.0	10.0	76.2	14.0	.6	
9-08-75	810	5.85	7.7	14.7	49.0	1.0	72.4	11.5	23.8	26.5	8.7	70.4	15.0	.5	
9-15-75	370	5.91	8.8	14.8	46.0	.9	70.5	11.3	22.4	31.2	8.6	73.6	13.0	.6	
9-22-75	1820	5.77	9.1	14.6	45.2	.8	69.8	13.4	21.2	25.0	8.6	68.2	13.0	.6	
9-29-75	30	5.70	6.0	15.0	44.4	.8	66.2	9.2	22.3	28.8	6.8	67.0	14.0	.4	
10-07-75	3930	5.44	10.5	13.9	39.2	.8	64.4	16.0	18.8	26.0	5.6	66.4	11.0	.7	
10-22-75	170														

WATER ANALYSES, VACUUM EXTRACTORS, S-4

Date	Volume	EC	Ca	Mg	Na	K	Σ^+	HCO_3	Cl	SO_4	NO_3	Σ^-	SAR	Ca/Mg	Cl Ratio
7-31-73	1084	1.74	9.6	4.5	5.7	.2	19.9	10.2	6.7	2.3	.4	19.7	2.1	2.1	.35
8-24-73	220		18.0	8.2	10.0			13.7	12.8	5.8				2.2	.18
9-11-73	140	3.40	11.9	10.7	12.5	.3	35.4	13.0	16.7	6.2	.7	36.6	3.7	1.1	.14
4-27-74		3.73	13.2	13.6	13.5	.2	40.5	9.3	18.9	10.2	3.2	41.6	3.7	1.0	.12
6-05-74	630	4.30	19.7	11.2	16.1	.2	47.3	8.3	21.7	11.9	4.3	46.2	4.1	1.8	.11
10-16-74	62	4.60	23.7	12.2	17.1	.3	53.2	14.8	20.7	12.5	5.0	53.0	4.0	1.9	.11
10-25-74	20														
11-01-74	350	5.17	26.4	11.6	21.5	.1	59.6	9.1	22.0	18.7	10.8	60.6	4.9	2.3	.11
11-15-74	980	4.46	23.7	11.9	17.8	.3	53.7	15.1	20.3	10.6	5.5	51.4	4.2	2.0	.12
5-29-75	126	4.86	26.2	13.6	18.0	.3	58.1	8.1	26.4	14.5	7.2	56.2	4.0	1.9	
6-03-75	267	4.44	23.2	13.2	17.6	.3	54.3	15.0	20.7	13.5	5.0	54.3	4.1	1.8	
6-05-75	190	4.50	23.5	13.7	17.9	.3	55.4	15.4	20.4	15.2	4.6	55.7	4.2	1.7	
6-07-75	1030	4.33	22.4	12.2	16.4	.3	51.3	13.8	20.3	13.8	4.3	52.1	3.5	1.8	
6-16-75	2740	4.52	23.3	12.8	18.2	.3	54.7	15.6	19.9	14.8	3.7	53.9	4.3	1.8	
6-24-75	100	5.06	21.6	15.0	22.9	.4	60.0	9.9	25.7	17.9	6.3	59.8	5.4	1.4	
7-01-75	40	4.88	21.2	14.0	21.3	.4	56.9	7.5	25.3	18.7	4.7	56.2	5.1	1.5	
7-08-75	58	4.97	23.4	13.3	22.4	.4	59.5	13.4	23.6	16.2	6.0	59.2	5.2	1.8	
7-15-75	260	4.77	25.3	11.8	20.5	.3	57.9	17.2	20.6	15.5	5.4	58.7	4.8	2.1	
7-18-75	250	4.56	23.5	11.7	19.1	.3	54.6	17.8	19.0	14.8	4.9	56.5	4.5	2.0	

WATER ANALYSES, VACUUM EXTRACTORS, S-4

Date	Volume	EC	Ca	Mg	Na	K	Σ^+	HCO_3	Cl	SO_4	NO_3	Σ^-	SAR	Ca/Mg	Cl Ratio
7-28-75	250	4.59	24.1	15.7	20.5	.3	60.6	20.7	19.1	16.0	4.7	60.5	4.6	1.5	
9-22-75	170	2.77	13.0	6.7	11.8	.2	31.8	15.6	6.5	6.3	3.5	32.0	3.8	1.9	
10-07-75	455	4.99	25.4	15.5	20.7	.3	61.8	20.4	20.8	19.3	3.8	64.2	4.6	1.6	
10-22-75	150	4.76	18.6	16.7	21.6	.3	57.2	11.7	23.7	20.2	.9	56.5	5.1	1.1	

WATER ANALYSES, VACUUM EXTRACTORS, S-5

Date	Volume	EC	Ca	Mg	Na	K	Σ^+	HCO_3	Cl	SO_4	NO_3	Σ^-	SAR	Ca/Mg	Cl Ratio
7-31-73	1520	1.66	12.3	3.4	3.8	Tr	19.5	6.6	3.5	8.2	.6	19.0	1.4	3.7	.66
8-07-73	2270	1.65	11.4	3.1	3.7	.1	18.3	6.6	3.4	8.2	.6	18.8	1.4	3.7	.69
8-14-73	48	1.64	10.4	3.1	4.4	.1	18.0	7.2	3.5	7.1	.4	18.2	1.7	3.4	.68
7-01-75	1000	2.84	15.7	5.9	11.5	.2	33.3	11.8	9.4	8.8	3.2	33.2	3.5	2.7	
7-08-75	933	2.95	15.4	6.4	11.8	.2	33.8	13.7	9.6	7.4	2.8	33.5	3.6	2.4	
7-14-75	1140	2.79	15.2	6.2	11.0	.2	32.7	15.0	8.3	7.5	2.0	32.8	3.4	2.4	
7-18-75	440	2.84	15.6	8.4	11.2	.2	35.4	16.4	8.2	8.3	2.1	35.0	3.2	1.8	
7-28-75	1450	2.48	14.1	8.0	9.1	.2	31.4	17.6	6.1	6.0	1.1	30.8	2.7	1.8	
8-05-75	500	2.57	14.8	8.5	9.6	.2	33.2	19.9	6.3	7.0	.4	33.6	2.8	1.7	
8-11-75	1360	2.36	13.6	7.3	8.7	.2	29.8	17.1	5.6	6.5	.5	29.6	2.7	1.9	
8-18-75	520	2.58	14.5	7.7	9.6	.2	32.0	18.7	6.2	7.2	.4	32.4	2.9	1.9	
8-25-75	820	2.57	13.9	7.5	8.9	.2	30.6	16.1	6.5	6.7	.3	29.5	2.7	1.9	
9-02-75	530	2.39	11.5	7.5	9.1	.2	28.3	17.7	6.3	7.9	.7	32.6			
9-08-75	660	2.54	14.0	8.1	9.8	.2	32.1	18.0	6.8	10.4	.5	35.7			
9-15-75	530	2.58	15.7	7.2	9.2	.2	32.3	18.2	6.7	8.3	.05	33.2	3.0	2.2	
9-22-75	260	2.64	14.3	7.2	9.5	.2	31.2	18.1	6.8	7.3	.1	32.3	2.9	2.0	
9-29-75	55	2.18	7.9	7.4	9.4	.2	24.9	10.5	6.8	7.2	.4	25.0	3.4	1.1	

WATER ANALYSES, VACUUM EXTRACTORS, S-5

Date	Volume	EC	Ca	Mg	Na	K	Σ^+	HCO_3	Cl	SO_4	NO_3	Σ^-	SAR	Ca/Mg	Cl Ratio
10-07-75	1855	2.61	15.1	7.2	8.8	.2	31.3	17.4	6.8	7.6	.4	32.2	2.7	2.1	
10-22-75	120	2.20	5.6	8.0	9.8	.2	23.6	8.1	7.5	8.4	.1	24.1	3.7	.7	

WATER ANALYSES, VACUUM EXTRACTORS, S-6

Date	Volume	EC	Ca	Mg	Na	K	Σ^+	HCO_3	Cl	SO_4	NO_3	Σ^-	SAR	Ca/Mg	Cl Ratio
7-31-73	290	2.54	12.0	6.8	8.6	.2	27.6	8.3	12.5	6.6	.7	28.1	2.8	1.8	.19
4-27-74		7.43	36.8	25.0	27.6	.2	89.6	8.8	36.3	28.2	13.6	87.0	5.0	1.5	.06
6-05-74	680	8.88	49.6	33.0	30.9	.2	113.7	9.6	43.4	40.8	17.4	111.2	4.8	1.4	.05
6-12-74	612	7.57	40.5	20.8	28.7	.2	90.2	8.6	34.8	26.6	17.4	87.5	5.2	2.0	.07
6-19-74	280	7.83	43.2	24.9	28.6	.1	96.7	9.4	33.4	28.1	21.5	92.4	4.9	1.7	.07
7-09-74	309	8.33	42.0	27.7	30.2	.3	100.2	11.3	34.5	28.9	23.5	98.2	5.1	1.5	.07
7-17-74	104	7.86	39.4	27.2	30.2	.3	97.0	13.3	32.2	27.3	26.2	99.0	5.2	1.4	.07
7-24-74	119	7.82	38.6	23.7	28.7	.2	91.2	15.8	30.9	23.4	21.9	92.0	5.2	1.6	.08
7-31-74	72	8.45	43.8	26.9	32.1	.3	103.1	13.5	34.3	31.4	22.8	102.0	5.4	1.6	.07
10-05-74	1920	12.10	59.1	40.7	39.5	.2	139.5	14.5	47.1	40.6	37.3	139.4	5.6	1.4	.05
10-16-74	1460	12.60	61.6	42.5	40.7	.2	144.9	14.4	46.9	45.4	40.5	147.1	5.6	1.4	.05
10-24-74	1790	10.60	56.5	37.5	43.3	.2	137.4	13.4	40.8	42.9	40.1	137.2	6.3	1.5	.06
11-02-74	1020	11.00	58.6	40.8	44.1	.2	143.6	13.4	42.8	43.5	43.4	143.1	6.2	1.4	.06
11-15-74	430	8.98	49.2	35.4	37.7	.2	122.5	13.2	34.0	44.8	27.4	119.4	5.8	1.4	.07
5-29-75	840	9.25	53.5	35.9	39.3	.2	128.9	14.0	35.4	50.8	28.9	129.2	5.9	1.5	
6-03-75*	3165	7.24	39.5	36.7	37.0	.2	115.4	14.3	35.0	40.6	25.4	115.3			
6-05-75	56	9.59	53.2	37.2	40.9	.2	131.5	16.9	36.7	53.6	27.7	134.9	6.1	1.4	

*Not USSL data

WATER ANALYSES, VACUUM EXTRACTORS, S-6

Date	Volume	EC	Ca	Mg	Na	K	Σ^+	HCO_3	Cl	SO_4	NO_3	Σ^-	SAR	Ca/Mg	Cl Ratio
6-16-75	730	8.16	42.4	30.8	39.8	.2	113.1	18.6	28.3	45.8	26.3	113.0	6.6	1.4	
6-24-75	200	8.34	39.3	34.4	42.9	.2	116.8	16.6	29.2	53.3	16.2	115.3	7.1	1.1	
7-01-75	20	8.87	37.6	36.1	51.6	.2	125.5	7.0	35.8	60.9	18.7	122.4	8.5	1.1	
7-08-75	574	7.70	39.6	25.7	38.2	.2	103.7	19.3	25.3	44.3	13.3	102.3	6.7	1.5	
7-14-75	1620	7.17	38.5	23.2	36.4	.2	98.3	20.0	22.8	43.0	11.6	97.3	6.5	1.7	
7-18-75	770	6.98	36.6	23.2	35.1	.2	95.2	19.3	21.8	44.4	9.6	95.2	6.4	1.6	
7-28-75	1480	6.43	33.7	27.2	31.3	.2	92.3	21.8	20.1	41.8	8.6	92.2	5.7	1.2	
8-11-75	900	5.88	30.6	24.8	31.9	.2	87.6	23.2	17.1	38.5	6.8	85.6	6.1	1.2	
8-18-75	950	5.68	28.5	21.9	29.4	.1	79.9	23.5	15.8	35.9	4.6	79.8	5.9	1.3	
8-25-75	1040	5.43	25.9	19.6	30.6	.1	76.2	26.0	14.4	31.2	4.2	75.8	6.4	1.3	
9-02-75	2840	4.01	19.9	15.0	23.4	.2	58.6	22.5	11.0	21.9	3.2	58.5	5.6	1.3	
9-08-75	2430	4.07	18.6	14.8	20.9	.1	54.4	22.2	10.3	20.0	1.8	54.4	5.1	1.2	
9-15-75	1180	4.30	19.9	15.3	21.5	.1	56.8	21.7	10.2	23.0	1.2	56.2	5.1	1.3	
9-22-75	1000	4.44	21.0	17.3	21.6	.1	60.0	22.4	10.4	26.2	1.8	60.8	4.9	1.2	
9-29-75	45	4.28	19.3	16.8	21.5	.1	57.7	20.3	10.7	27.2	1.5	59.6	5.1	1.1	
10-07-75	3920	3.83	18.5	14.3	17.4	.1	50.2	19.4	9.1	20.9	1.0	50.4	4.3	1.3	
10-22-75	140	3.57	10.5	14.6	18.4	.1	43.6	9.7	9.5	22.7	.2	42.1	5.2	.7	

TABLE A2

DRILL HOLE WATER LEVEL DATA, LITTLE SALT WASH--ADOBE WASH AREA OF THE GRAND VALLEY, 1974-1975

Date	Drill Hole										
	1	2	3	8_s	9_s	10_s	11A	$11B_s$	12	13	15
	Water Level (feet)										
8/23/74	5.5	--	11.5								
9/12/74	--	12.0	--	21.0	16.0	14.0	17.0	11.5	7.0	10.5	9.0
10/31/74*	6.0	10.0	6.4	21.6	17.8	14.8	10.7	11.8	7.2	6.4	7.6
12/5/74	8.5	12.0	7.0	22.9	--	17.0	11.0	12.5	7.5	7.0	8.0
12/17/74											
1/23/75											
1/31/75											
2/14/75	8.6	--	8.6	dry	dry	--	11.3	12.7	8.6	12.0	8.4
4/15/75	9.1	12.8	7.9	dry	dry	15.7	11.5	13.1	4.7	12.0	9.2
4/25/75**	--	12.5	6.0	dry	dry	15.7	11.2	12.8	4.9	12.8	--
4/30/75	--	12.3	5.9	dry	dry	15.2	11.2	12.8	7.1	11.6	--
5/2/75	4.5	--	5.4	dry	dry	16.8	11.2	12.6	12.1	11.6	--
5/20/75	2.5	10.3	5.4	dry	dry	14.6	10.7	12.0	6.3	10.9	8.5
6/4/75	4.1	10.0	5.4	dry	21.5	13.8	10.6	4.7	6.3	10.6	8.4
6/25/75	2.7	9.6	5.4	dry	20.8	14.4	10.6	12.3	8.7	10.2	8.2
8/7/75	2.7	9.2	6.2	23.1	18.7	13.5	15.7	12.4	5.9	10.5	7.5
9/4/75	3.5	9.4	6.2	21.9	17.7	14.0	10.6	12.2	7.8	10.9	7.3
10/9/75	4.0	9.5	--	22.2	17.0	14.3	10.4	11.5	6.9	11.1	7.0
11/18/75	7.8	10.5	8.5	dry	dry	--	11.3	12.5	7.0	12.0	7.0
12/17/75	dry	9.1	8.5	dry	D	16.0	10.5	12.5	7.5	11.2	6.5
1/12/76	8.0	17.5	8.7	D	D	17.0	17.0	18.5	7.5	13.0	8.5
2/17/76	8.5	12.2	9.0	D	D	16.5	11.5	13.0	6.5	12.0	8.5
3/15/76	9.5	13.3	9.0	D	D	17.5	11.5	11.0	7.0	13.0	7.0
4/19/76	6.5	12.0	6.0	D	D	16.0	11.0	13.0	7.0	12.2	8.5

DRILL HOLE WATER LEVEL DATA, LITTLE SALT WASH--ADOBE WASH AREA OF THE GRAND VALLEY, 1974-1975

Date	Drill Hole										
	16	17	18A	18B	19_1	19_2	20_1	20_2	21	22_1	22_2
	Water Level (feet)										
8/23/74											
9/12/74	4.0	7.0									
10/31/74*	3.6	12.2									
12/5/74	7.5	15.0									
12/17/74			10.1	17.3	3.8	3.8	7.0	7.0	9.0	6.0	6.0
1/23/75				19.0	6.0	--	8.8	--	10.8	7.0	--
1/31/75			10.8	18.3	6.0	5.2	8.8	8.8	10.7	7.0	7.0
2/14/75	9.1	15.6	11.0	15.3	5.7	5.8	8.9	9.9	10.6	6.8	6.8
4/15/75	9.5	15.7	11.7	19.4	6.9	5.6	10.0	10.0	11.0	7.3	7.6
4/25/75**	7.1	15.7									
4/30/75	5.8	15.7									
5/2/75	6.5	15.9	--	--	6.7	5.3	10.1	10.1	10.7	--	--
5/20/75	3.5	14.9	11.8	12.0	4.3	3.3	9.0	9.0	9.7	4.5	4.5
6/4/75	3.5	14.8	11.9	17.5	4.0	3.5	6.1	6.8	10.0	4.3	4.2
6/25/75	3.6	14.2	11.9	17.5	4.0	3.8	6.9	6.8	10.7	4.2	4.4
8/7/75	3.3	11.8	12.0	16.3	2.9	3.3	4.6	4.7	11.2	4.0	4.0
9/4/75	3.2	12.0	12.2	15.8	2.8	3.2	5.2	5.2	10.8	3.5	3.5
10/9/75	3.2	12.1	13.6	16.6	3.4	3.3	6.9	6.6	11.0	3.9	4.0
11/18/75	6.5	22.0	13.5	17.5	4.5	3.8	7.5	7.5	11.5	5.0	4.5
12/17/75	8.0	D	11.0	18.0	4.8	4.5	8.5	8.0	11.0	6.5	5.5
1/12/76	8.5	D	13.0	20.0	6.0	6.0	11.0	10.0	11.5	7.0	7.0
2/17/76	9.5	D	18.5	13.0	6.2	6.3	10.0	9.5	11.0	7.5	6.5
3/15/76	10.0	D	19.0	14.0	--	--	10.0	6.0	12.0	7.0	4.0
4/19/76	5.0	D	19.5	13.0	5.0	5.0	10.0	10.0	11.3	7.0	7.0

*Government Highline Canal turned out October 14, 1974

**Government Highline Canal turned in April 14, 1975 (at Little Salt Wash 0700, April 15)

Subscript s indicates drill holes in which artesian water zone was encountered in Mancos Shale.

Subscripts 1 and 2 indicate drill holes in which two different lengths of PVC casing were placed.

TABLE A3

WATER SAMPLES, ARS WELLS (SCHNEIDER), 6/25/75, GRAND JUNCTION, COLORADO

Well No.	pH	EC	me/1							
			Ca	Mg	Na	K	HCO_3	Cl	NO_3	SO_4
1	7.85	0.74	2.72	0.81	2.61	.087	3.70	1.94	.138	0.91
2	7.76	7.63	14.97	24.18	78.26	.407	10.70	15.72	1.135	86.25
3	7.51	3.14	5.99	4.93	23.77	.299	12.76	3.88	.184	20.50
9	7.97	3.35	24.50	8.55	6.09	.371	3.70	3.70	.531	34.25
10	7.56	3.91	24.16	11.82	10.87	.412	6.10	5.96	.330	36.25
11A	7.53	4.35	14.29	11.82	23.91	.274	9.00	10.32	.789	27.81
11B	7.56	5.24	18.21	13.86	29.13	.220	8.10	10.42	.700	45.50
12	7.91	18.50	13.97	49.34	379.35	.621	23.00	33.04	.795	365.63
13	7.40	4.69	15.97	14.88	23.77	.384	3.76	9.92	.375	41.87
15	7.65	15.90	17.30	117.19	189.13	.767	18.60	23.04	35.47	235.94
16	7.75	3.54	5.65	7.40	26.27	.203	14.36	8.72	.263	18.75
17	7.51	3.86	13.97	17.27	16.26	.217	7.20	5.98	.145	37.19
18-H*	7.88	3.93	18.06	16.81	16.89	.353	6.40	5.44	.199	40.50
18-L	7.59	5.53	9.65	13.16	46.29	.849	10.80	6.64	.795	50.63
19-H	7.67	5.24	11.98	14.39	38.16					
19-L	11.15	5.37	25.17	0.02	32.17	.481	3.80	11.52	.821	41.12
20-H	7.53	5.06	20.41	12.84	26.96	.281	9.20	21.52	.854	27.81
20-L	7.57	4.81	18.46	13.65	25.43	.286	9.00	19.24	.758	25.62
21	7.69	1.92	6.24	4.07	7.83	.136	5.00	3.30	.222	9.50
22-H	7.22	5.40	13.31	21.13	33.78	.361	3.90	7.80	2.224	56.25
22-L	7.18	4.77	14.64	14.39	26.27	.299	2.40	7.42	.422	42.37

*H, 1" casing, deep
L, 4" casing, shallow

WATER SAMPLES FROM ARS WELLS (SCHNEIDER), 8/7/75, GRAND JUNCTION

			me/1								
Well No.	pH	EC	Ca	Mg	Na	K	HCO_3	Cl	NO_3	SO_4	$pCaSO_4$
1	7.44	1.15	5.49	3.29	3.26	.084	6.70	2.27	.158	6.42	5.68
2	7.82	8.12	15.47	32.90	95.65	.537	13.50	19.90	1.443	111.74	4.73
3	7.74	3.05	7.73	10.69	20.43	.488	15.00	5.10	1.722	17.05	5.39
9	7.28	3.08	17.47	16.45	6.09	.276	3.80	3.28	.173	35.51	4.81
10	7.57	3.26	18.46	16.04	11.09	.355	7.50	5.30	.206	33.14	4.83
11A	7.74	3.68	11.48	12.34	24.56	.243	8.30	9.96	.419	28.12	5.08
11B	7.64	4.49	16.47	13.98	29.57	.174	8.70	10.52	.522	44.24	5.21
12	7.89	18.42	13.97	50.16	373.91	.660	23.00	30.66	.438	406.96	4.66
13	7.64	3.87	16.97	14.80	17.61	.338	4.40	9.04	.206	37.88	4.83
15	7.65	14.52	16.97	119.24	208.70	.794	18.40	21.56	34.775	280.97	4.62
16	7.82	4.29	6.49	9.87	38.48	.315	17.80	10.54	.236	26.99	5.36
17	7.58	3.03	10.98	12.34	13.91	.230	9.40	5.34	.166	24.62	5.11
18-L*	7.76	5.11	10.48	13.16	43.70	.852	11.80	6.86	.623	49.72	5.00
18-H	7.29	3.53	14.72	14.39	15.22	.445	5.80	4.80	.478	36.46	4.89
19-H	7.57	4.82	12.48	14.80	35.87	.514	4.40	10.54	.307	50.89	4.90
19-L	8.64	4.16	15.22	1.64	29.56	.488	1.00	11.10	.401	38.35	4.84
20-H	7.63	4.46	16.22	12.58	27.30	.269	9.10	21.36	.438	27.70	4.98
20-L	7.71	4.21	13.67	12.50	23.70	.269	8.40	19.30	.623	24.72	5.07
21	7.84	1.58	5.49	4.11	6.74	.107	5.80	4.40	.145	9.38	5.58
22-H	7.32	4.23	15.97	17.60	23.70	.371	4.50	7.62	.236	47.73	4.81
22-L	7.20	4.32	17.02	14.80	26.87	.371	3.30	8.34	.189	48.77	4.77

*H, 1" casing, deep
L, 4" casing, shallow

WATER SAMPLES FROM ARS WELLS (SCHNEIDER), 10/12/75, GRAND JUNCTION

Well No.	pH	EC	me/1								$pCaSO_4$
			Ca	Mg	Na	K	HCO_3	Cl	NO_3	SO_4	
1	7.18	2.70	13.42	6.77	11.03	.21	6.80	5.18	.257	19.81	5.06
2	7.82	12.61	22.50	55.89	167.83	.80	19.60	26.00	1.39	200.31	4.53
3	7.75	1.64	5.61	3.27	7.90	.27	5.50	4.86	.267	8.13	5.63
9	7.54	3.84	21.49	22.80	11.03	.43	3.50	3.98	.824	44.62	4.71
10	7.50	3.55	24.26	13.35	9.77	.42	7.20	5.34	.354	33.14	4.73
11A	7.48	3.93	14.94	13.14	23.55	.29	9.20	9.88	.622	28.54	4.98
11B	7.71	4.85	19.54	14.38	32.12	.19	7.80	10.38	.702	45.70	4.76
12	7.83	21.28	18.28	53.41	456.30	.82	23.40	32.84	.647	463.75	4.54
13	7.59	4.18	19.78	14.38	20.53	.41	3.40	8.84	.416	43.24	4.74
15	7.69	16.19	20.11	122.29	228.15	.97	18.40	22.00	36.26	282.19	4.56
16	7.73	4.23	9.14	10.88	36.07	.33	17.60	10.46	.451	24.41	5.26
17	7.44	3.78	19.72	17.25	12.28	.30	10.30	9.64	.340	29.00	4.88
18-H*	7.54	4.04	21.99	17.87	17.29	.33	6.40	5.90	.257	43.70	4.71
18-L	7.86	5.48	14.18	14.58	49.22	1.02	12.36	6.88	.824	57.81	4.85
19-L	7.77	3.80	16.95	11.91	21.67	.20	6.96	8.36	.400	32.68	4.88
19-H	7.69	1.29	4.35	2.66	6.02	.28	3.80	3.96	.218	6.82	5.75
20-L	7.68	4.26	16.95	11.50	24.80	.25	10.20	18.36	.893	23.03	5.02
20-H	7.64	4.21	16.70	11.29	24.80	.24	10.00	17.82	.893	22.11	5.03
21	7.79	1.59	6.11	3.89	6.02	.13	5.36	3.30	.186	8.81	5.56
22-L	7.24	4.63	20.22	16.23	27.30	.36	4.60	7.78	.340	47.84	4.72
22-H	7.48	1.19	3.59	1.83	5.39	.27	3.80	3.86	.201	5.68	5.87

*H, 1" casing, deep
L, 4" casing, shallow

WATER SAMPLES FROM ARS WELLS (SCHNEIDER), 11/18/75, GRAND JUNCTION

Well No.	pH	EC	me/1 Ca	Mg	Na	K	HCO_3	Cl	NO_3	SO_4	$pCaSO_4$
1	7.60	1.50	3.84	3.62	6.35	.22	5.90	4.06	.16	7.05	5.82
2	7.35	12.52	17.13	53.27	155.22	.73	18.10	24.42	1.87	165.13	4.68
3	7.17	2.07	6.65	5.87	9.88	.23	7.30	4.36	.42	14.12	5.41
10	6.98	4.19	20.37	13.93	17.33	.45	7.50	4.88	.45	39.42	4.76
11A	6.75	4.10	11.89	12.93	25.76	.29	9.20	9.40	.81	28.86	5.07
11B	7.08	5.08	18.62	15.75	31.59	.20	7.80	9.62	.87	45.39	4.79
12	7.44	20.49	15.88	45.68	388.04	.81	21.00	28.58	1.37	371.03	4.63
13	6.64	4.32	19.37	15.75	18.30	.33	3.20	7.82	.42	39.88	4.78
16	7.14	3.66	6.15	10.11	27.70	.32	17.00	8.60	.48	15.79	5.54
17	7.47	3.21	14.82	14.31	11.09	.26	7.30	5.10	.15	24.66	5.00
18-H*	6.97	4.30	18.87	18.36	18.30	.36	6.50	4.88	.40	40.80	4.79
18-L	7.40	6.71	13.63	20.09	59.52	.98	12.70	7.38	2.94	62.43	4.88
19-H	7.06	5.39	14.63	15.83	39.70	.53	3.80	9.50	.71	52.46	4.85
19-L	7.32	4.02	14.63	12.32	23.49	.25	7.00	7.70	.57	32.99	4.94
20-H	7.02	4.52	13.38	12.12	27.37	.29	9.40	17.74	1.04	23.34	5.11
21	7.34	1.79	6.40	4.26	7.29	.16	5.00	2.54	.35	12.87	5.42
22-H	6.83	4.80	15.13	19.17	26.08	.41	5.00	6.18	.48	46.77	5.31
22-L	6.88	4.94	16.88	15.95	28.02	.36	3.10	7.28	.43	50.44	4.81

*H, 1" casing, deep
L, 4" casing, shallow

WATER SAMPLES FROM ARS WELLS (SCHNEIDER), 12/17/75, GRAND JUNCTION

Well			me/1								
No.	pH	EC	Ca	Mg	Na	K	HCO_3	Cl	NO_3	SO_4	$pCaSO_4$
2	7.71	12.86	22.34	52.04	164.13	.73	18.00	24.10	1.43	191.50	4.54
3	7.52	3.95	10.15	6.70	32.77	.25	8.10	6.26	.275	30.54	5.10
10	7.29	3.94	25.66	13.39	13.40	.48	5.36	5.68	.246	41.60	4.65
11A	7.20	4.11	16.06	12.78	25.88	.25	9.20	9.84	.500	32.88	4.91
11B	7.45	5.13	23.81	15.22	31.48	.21	7.36	9.84	.464	53.04	4.65
12	7.78	21.79	20.49	49.60	405.17	.74	21.76	30.60	.784	416.47	4.51
13	7.41	4.25	23.45	14.91	18.57	.34	3.64	8.28	.296	46.69	4.65
15	7.68	17.37	22.52	127.81	241.61	.89	18.20	21.82	33.14	282.06	4.53
16	7.63	4.27	9.04	11.87	33.63	.29	16.80	9.70	.371	24.12	5.27
18-H*	7.43	4.34	23.45	17.96	19.43	.39	6.60	5.54	.307	50.41	4.65
18-L	7.29	6.53	15.51	20.39	58.65	1.21	11.96	7.30	3.02	70.87	4.79
19-L	7.63	4.10	18.65	12.48	22.87	.26	6.50	8.00	.482	36.39	4.82
20-L	7.40	4.49	16.80	12.18	26.74	.26	8.60	18.14	.877	24.99	5.00
20-H	7.47	4.55	17.17	11.87	26.74	.26	9.24	18.50	.814	25.28	4.99
21	7.56	2.71	9.04	6.39	17.27	.18	5.60	4.74	.204	20.61	5.20

*H, 1" casing, deep
L, 4" casing, shallow

WATER SAMPLES FROM ARS WELLS (SCHNEIDER), 3/16/76, GRAND JUNCTION

Well No.	pH	EC	Ca	Mg	Na	K	HCO_3	Cl	NO_3	SO_4	$pCaSO_4$
			me/1								
1	7.46	1.22	4.25	1.87	3.92	.23	5.50	2.08	.622	3.53	6.00
2	7.47	10.31	16.88	45.43	116.90	.59	14.70	17.88	1.27	145.71	4.67
3	7.24	2.32	8.06	4.72	12.35	.21	8.10	4.80	.387	14.05	5.35
10	7.20	3.80	20.69	14.08	14.04	.40	7.20	5.22	.387	37.95	4.75
11A	7.43	4.03	12.35	13.68	25.43	.24	9.00	9.02	.789	32.88	5.01
11B	7.47	4.91	19.02	15.30	30.91	.20	8.04	9.80	.713	47.88	4.76
12	7.74	20.15	16.16	51.53	393.46	.67	20.24	28.40	1.22	402.66	4.60
13	7.50	4.61	19.50	17.75	23.32	.31	4.00	8.58	.401	48.95	4.73
15	7.48	16.56	18.55	120.48	228.98	.84	18.20	21.54	26.70	258.66	4.62
16	7.57	3.24	5.68	8.79	25.43	.28	15.60	7.24	.401	16.94	5.52
18-L*	7.71	5.51	12.35	15.30	48.33	.92	11.80	6.32	1.03	54.33	4.92
18-H	7.19	3.97	18.07	17.75	17.42	.36	5.56	4.48	.903	43.22	4.78
19-L	7.63	6.43	14.02	19.38	59.29	.56	4.80	10.54	.491	76.99	4.80
19-H	7.67	3.95	13.78	12.45	23.32	.25	5.90	7.64	.429	33.77	4.95
20-L	7.46	4.50	13.78	12.45	27.96	.30	10.00	16.94	1.03	26.00	5.06
20-H	7.65	4.35	11.87	12.05	26.69	.26	7.40	17.70	1.18	24.62	5.13
21	7.67	2.45	6.16	5.53	15.31	.17	6.00	3.84	.225	18.12	5.38
22-L	7.31	4.45	15.21	18.56	25.43	.36	4.30	5.94	.276	49.76	4.82
22-H	7.51	4.85	17.12	16.93	29.65	.31	3.80	6.68	.350	51.37	4.77

*H, 1" casing, deep
L, 4" casing, shallow

TABLE A4 WATER SAMPLES FROM DRAINS, 12/17/75, GRAND JUNCTION

Drain	Site No.*	pH	EC	Ca	Mg	Na	K	HCO_3	Cl	NO_3	SO_4	$pCaSO_4$
				me/1								
Lewis	1	7.62	3.93	24.74	22.22	11.25	.25	6.16	4.58	.265	45.45	4.65
	2	7.64	3.99	23.08	22.22	13.83	.28	5.60	5.32	.344	44.57	4.69
	3	7.75	4.54	23.45	26.48	18.57	.31	6.70	6.08	.626	51.29	4.66
Indian	1	7.75	4.04	24.00	18.56	17.27	.31	5.20	4.70	.727	46.46	4.65
	2	7.72	4.25	23.45	19.78	19.86	.28	4.90	5.66	.581	47.49	4.66
	3	7.72	5.08	23.08	28.91	26.74	.39	6.46	7.50	.877	62.68	4.63
Persigo	Canal	7.48	3.33	26.40	7.00	10.82	.21	3.20	3.16	.228	35.24	4.65
	1	7.69	3.98	24.74	16.13	15.12	.31	4.64	4.30	.319	42.77	4.66
	2	7.64	4.36	23.08	21.61	19.43	.34	5.56	4.88	.539	49.24	4.67
	3	7.63	4.84	24.18	23.74	23.73	.34	5.60	6.46	.845	55.67	4.63
Hunter	1	7.64	4.34	23.08	20.69	19.86	.35	5.10	4.16	.447	52.17	4.65
	2	7.79	4.18	22.34	22.22	16.84	.34	4.20	4.96	.464	57.70	4.68
	3	7.70	4.25	23.81	21.00	17.27	.31	6.16	5.40	.603	45.96	4.67
Adobe	1	7.73	4.05	24.18	15.52	19.43	.31	5.40	4.02	.357	46.32	4.65
	1.5	7.88	3.34	24.00	13.09	9.10	.26	3.00	3.28	.675	36.98	4.68
	2	7.64	3.83	23.81	17.35	14.69	.31	5.00	4.50	.603	43.22	4.67
	3	7.79	4.10	21.23	18.26	19.00	.29	4.40	5.16	.784	44.14	4.71
	4	7.74	4.30	22.34	18.56	22.01	.31	7.40	6.16	.877	45.53	4.70
Little Salt	1	7.90	3.08	12.00	10.65	18.13	.19	6.00	3.20	.603	25.87	5.05
	2	7.59	3.74	17.54	11.87	12.97	.19	5.56	4.44	.539	35.22	4.83
	3	7.58	4.07	22.34	14.31	19.43	.28	6.00	4.54	.560	42.29	4.70
	3.5	7.96	4.11	19.75	13.70	23.73	.26	6.80	5.08	.519	40.91	4.76
	4	7.65	4.36	19.20	14.00	26.74	.23	5.80	5.64	.539	45.07	4.75
Big Salt	1 E	7.60	4.16	25.29	17.35	17.27	.34	6.80	4.10	.415	47.38	4.63
	1 W	7.54	3.34	16.06	12.48	15.55	.19	6.04	3.36	.344	30.27	4.90
	2 E	7.70	3.83	22.71	16.74	12.54	.28	5.20	3.54	.500	43.11	4.68
	2 W	7.57	3.71	17.54	16.13	16.84	.22	5.80	4.84	.701	34.93	4.85
	3 (main)	7.52	3.52	19.38	15.52	12.97	.25	6.20	4.22	.464	33.76	4.81

*As site number increases, water moves from near Highline Canal to Colorado River.

WATER SAMPLES FROM DRAINS, 3/3/76, GRAND JUNCTION

				me/1								
Drain	Site No.*	pH	EC	Ca	Mg	Na	K	HCO_3	Cl	NO_3	SO_4	$pCaSO_4$
Lewis	1	7.64	3.85	20.06	23.36	11.74	.28	6.10	4.94	.230	43.09	4.75
	2	7.65	4.18	18.94	25.21	14.83	.33	5.60	5.24	.170	48.24	4.75
	3	7.71	4.79	19.06	31.17	21.67	.38	7.40	6.72	.599	57.03	4.73
Indian	1	7.66	4.04	19.19	19.24	15.48	.36	5.10	4.20	.371	44.91	4.75
	2	7.08	2.59	10.83	10.61	11.41	.29	3.00	2.88	.101	24.29	4.08
	2.5	7.39	4.96	17.81	33.02	25.91	.45	8.60	7.56	.442	61.58	4.74
	3	7.68	5.09	18.19	31.17	28.04	.43	6.60	7.56	.599	64.00	4.72
Persigo	1	7.66	3.96	20.06	18.42	14.83	.33	4.76	4.42	.202	46.61	4.71
	2	7.62	4.42	19.81	22.74	19.07	.35	5.64	5.82	.340	53.77	4.70
	3	7.67	4.81	19.31	24.79	24.61	.38	5.50	6.94	.599	57.91	4.71
Hunter	2	7.70	4.26	19.31	23.36	17.93	.40	6.44	5.88	.340	50.97	4.73
	3	7.57	4.34	19.06	22.53	19.07	.36	6.04	5.52	.442	49.76	4.74
Adobe	1	7.66	4.38	19.69	18.01	22.33	.35	5.60	4.56	.220	50.97	4.71
	1.5	7.64	3.39	21.06	13.90	9.46	.32	4.30	3.90	.549	37.63	4.73
	2	7.64	3.92	19.94	18.83	15.15	.25	5.56	5.18	.388	45.82	4.72
	3	7.66	4.26	17.94	19.65	21.67	.33	5.80	6.10	.549	48.85	4.76
	4	7.74	4.42	16.69	18.83	25.26	.35	6.36	6.40	.653	47.33	4.80
Little Salt	1	7.73	2.59	7.83	7.94	16.46	.23	5.80	3.06	.312	20.35	5.26
	2	7.76	3.10	12.08	8.96	17.61	.23	4.80	3.22	.251	27.33	5.02
	3	7.69	3.00	13.82	9.58	14.50	.24	5.40	3.36	.251	27.63	4.96
	3.5	7.64	2.87	10.33	7.73	17.28	.23	5.56	3.24	.211	25.81	5.09
	4	7.81	2.85	9.46	7.73	18.74	.23	5.30	2.56	.211	26.11	5.12
Big Salt	1 W	7.63	3.47	12.45	14.72	20.04	.23	5.76	3.18	.194	37.63	4.94
	1 E	7.56	4.03	19.94	18.83	17.93	.36	6.20	4.86	.274	47.63	4.72
	2 W	7.56	3.42	12.95	15.34	16.78	.24	6.40	4.70	.340	34.30	4.96
	2 E	7.62	3.66	18.44	17.19	13.37	.31	5.90	4.46	.326	40.83	4.78
	3 (main)	7.57	3.28	14.07	15.13	13.37	.28	6.10	4.00	.274	33.99	4.92

*As site number increases, water moves from near Highline Canal to Colorado River.