Preliminary Assessment of Specific Conductance and Total Dissolved Solids Loading Rates in Agricultural Drainwater of the Carson Division of the Newlands Project, Churchill County, Nevada

A report of the study "stillwater Wildlife Management Area Contaminant Loading"
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FINAL REPORT

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Abstract

Section 206 of the Truckee-Carson-pyramid Lake Water Rights Settlement Act (P.L. 101-618, November 1990) (Act) authorized the purchase of water rights to support a long-term average of 25,000 acres of wetlands in Lahontan Valley, Nevada. The U.S. Fish and Wildlife Service, the lead Federal agency responsible for implementation of this section of the Act, is restricting purchases to agricultural water rights in the Carson Division of the Newlands Project. Acquisition of agricultural water rights could enhance wetland habitat conditions by securing a water supply and by reducing total dissolved solids and trace elements in agricultural drainwater entering the wetlands. Because the quality of agricultural drainwater in the Newlands Project is variable, the overall benefit of water rights acquisition to wetlands can be increased by selective purchase of water rights associated with drains contributing relatively large loads of agriculturally-induced contaminants.

This study was implemented to identify drains and drain segments in the Carson Division of the Newlands Project contributing relatively larger loads of agricultural contaminants. To accomplish this task, specific conductance of drainwater and drain discharges were measured to calculate total dissolved solids loading rates. Existing data on arsenic, boron, and selenium concentrations in detritus collected from drains in the Newlands Project were evaluated to identify drains containing relatively higher concentrations. The magnitude of this study prohibited attainment of all objectives. Limited numbers of data points (each site was surveyed once) also reduced the value of the study findings. Further research needs and changes in study design are identified.

Key Words: Agricultural Drainage; Total Dissolved Solids; Trace Elements; Contaminant Loading; Lahontan Valley, Nevada
Introduction

The quantity and quality of wetlands in Lahontan Valley, Nevada, which include wetlands in Stillwater National Wildlife Refuge (NWR), Stillwater Wildlife Management Area (WMA), Carson Lake, and numerous other wetlands (Fig. 1), have declined considerably since intensive agricultural practices began shortly after 1900. As a consequence, the abundance and diversity of fish and wildlife in this area has declined. Agricultural water consumption, increased loading of dissolved solids, and mobilization and transport of potentially toxic trace elements from agricultural lands have been identified as factors contributing to these declines (Hoffman et al. 1990). Public concern for the loss of wetland habitat, degradation of wetland quality, and declines in wildlife abundance and species diversity prompted efforts to improve wetland conditions. In November 1990, the Truckee-Carson-pyramid Lake Water Rights Settlement Act (Public Law 101-618) (Act) was enacted by Congress. This Act contained measures to enhance fish and wildlife habitat associated with the Truckee and Carson River basins. Section 206 of the Act, authorized the purchase of water rights to sustain a long-term average of 25,000 acres of wetland habitat in the Lahontan Valley. The U.S. Fish and Wildlife Service (Service), the lead Federal agency responsible for implementing this section, has identified the preferred alternative as acquisition of agricultural water rights from the Newlands Project area near Fallon, Nevada (otherwise known as the Carson Division of the Newlands Project).

The transfer of agricultural water rights from the Carson Division of the Newlands Project may serve to improve wetland habitat conditions by increasing the volume of water entering wetlands and by reducing the load of agriculturally-induced contaminants discharged to wetlands. In the latter, a reduction of contaminant loading may result from the discontinuation of irrigation and the subsequent decrease in the mobilization, transport, and redistribution of dissolved solids, including trace elements. However, because agriculturally-induced contaminants are not homogeneously distributed throughout the Newlands Project area (Hoffman et al. 1990), it is believed that an even greater contaminant load reduction may be realized through selective agricultural land retirement. This study was implemented to investigate this possibility.

To identify areas within the Carson Division of the Newlands Project contributing proportionally greater loads of agriculturally-induced contaminants, specific conductance and discharge of agricultural drains were determined. This information was used to estimate total dissolved solids (TDS) loading rates in specific agricultural drains and laterals. These data were supplemented with trace element analyses of detritus collected from drains in the Newlands Project as part of the Department of the Interior Detailed Study of Agricultural Drainage in and near Stillwater WMA (Rowe et al. 1991), hereafter referred to as the detailed study.

Several unforeseen factors, including the extent and dynamics of the agricultural drainage system in the Newlands Project, staffing limitations, and shortages in agricultural water deliveries due to regional drought prevented the generation of information that is of immediate use to aid in water rights acquisition. Limited numbers of data points (each site was surveyed once) further reduce the value of study findings. Study findings are used to recommend changes in study methods and to recommend drainage areas in which to concentrate further research activities.

Background

Prior to agricultural development, wetlands covered approximately 172,000 acres in the Lahontan Valley (Hoffman et al. 1990). These wetlands, which included Carson Lake, Stillwater Marsh, and numerous smaller wetlands supported large and diverse assemblages of fish and wildlife. The Carson River, originating in the eastern slopes of the Sierra Nevada, was the primary
source of water (Fig. 1). Because Carson River discharge varied annually and seasonally, wetland size also varied.

In 1902, the Reclamation Service (the predecessor agency of the U.S. Bureau of Reclamation) established the Truckee-Carson Project, an extensive irrigation water delivery system in the Lahontan Valley. This project, later renamed the Newlands Project, allowed for the development of agricultural land near Fallon, Churchill County, Nevada (Fig. 1). Irrigation water to support the project was stored in Lahontan Reservoir on the Carson River. In addition to the Carson River, water was imported from the Truckee River through the Truckee Canal beginning in 1905. This approximately 60 kilometer (km) canal extends from Derby Dam on the Truckee River to Lahontan Reservoir (Fig. 1). A system of canals was constructed to deliver water from Lahontan Reservoir to flood irrigate an anticipated maximum of 73,000 acres. An extensive network of agricultural drains (over 550 km) was constructed to prevent soil saturation (U.S. Bureau of Reclamation 1991b). These drains discharge into adjacent wetland areas, including Carson Lake and Stillwater Marsh.

As a result of agricultural water consumption, the quantity of water entering the wetlands was reduced. The decreased amount of relatively fresh water and the increased discharge of agricultural drainwater to wetlands led to increased TDS concentrations. Hoffman et al. (1990) found that TDS concentrations in water passing through the Newlands Project increased by a factor of 10 or more. TDS concentrations in water released from Lahontan Reservoir typically ranged from 200 to 400 mg/L while concentrations in water from agricultural drains ranged from 566 to over 41,000 mg/L. Hoffman et al. (1990) also found elevated concentrations of certain constituents, including potentially toxic trace elements. In many cases, concentrations exceeded baseline concentrations and/or Federal and State criteria for the protection of aquatic life and/or the propagation of wildlife. Of primary concern were arsenic, boron, mercury, and selenium, in water, sediment, and/or biota collected from wetlands in Lahontan Valley. Other constituents, including chromium, copper, zinc, un-ionized ammonia, TDS, and sodium, approached levels of concern. Agricultural practices were identified as primary contributors to the mobilization and redistribution of these constituents. Adverse biological effects attributed to wetland habitat degradation included significant losses of wetland vegetation, declines in species abundance, and shifts in species composition (Hoffman et al. 1990). Contaminant loading associated with agricultural drainage also has been correlated with incidences of reproductive failure, developmental abnormalities, increased incidence of infectious diseases, long-term degradation of body conditions, and mortality of migratory birds (Hoffman et al. 1990; Moore et al. 1990).

During recent years, western Nevada has experienced drought. The 1991 water year (October 1, 1990 to September 31, 1991) was the fifth consecutive year of below-normal precipitation and run-off from the Sierra Nevada. As a result, Newlands Project water users received below-normal water deliveries. In 1990, water deliveries were delayed for 2 weeks at the beginning of the irrigation season and terminated 2 weeks before the end of the scheduled season. Deliveries were restricted to 163,407 acre-feet, or 70 percent of entitlements to water users (U.S. Bureau of Reclamation 1991a). In 1991, deliveries were delayed 5 weeks at the beginning of the irrigation season and terminated 4 weeks early. Deliveries were also suspended during a 2-week period in late September 1991. In 1991, 106,325 acre-feet, about 50 percent of entitlements, were delivered (U.S. Bureau of Reclamation 1992). Water shortages also prompted large-scale reuse of drainwater for irrigation. As a result, wetland size and quality were further diminished.

Methods

Field data were collected from October through December 1990, and June through August 1991. The original intent was to visit each site during both periods. However, because of the extent of the drain network, staffing limitations, and time constraints, each drain site was visited only once.
During these periods, discharge and specific conductance in most major drains flowing toward stillwater and Carson Lake area were measured. TJ Drain and Hunter Drain were excluded from this study because remedial measures for these drains were under consideration. In each drain, measurement sites in the main stem, laterals, and sublaterals were selected to determine discharge and specific conductance. Measurement sites were typically at points immediately upstream of the confluence of two or more drains, laterals, and sublaterals. In drain segments with large distances between lateral intersections (typically 1.5 km or more), measurement sites were established at intermediate locations. The actual number of acres served by major drains has not been determined and may be impossible to ascertain (Gene Harms, U.S. Bureau of Reclamation, pers. comm., 1990; in Lico 1992). Therefore, no attempt was made to correlate discharge and loading rates of each drain to agricultural acreage served.

Drainwater discharge (liters per second; LIs) was measured using methods described by Hamilton and Bergersen (1984). At each measurement site, a transect was placed perpendicular to the drainwater flow. The transect line was divided into increments based on width. Where drain flow width exceeded 4.6 meters (m), each increment represented 5 percent of the drain flow width. Where drain flow width was between 0.5 and 4.6 m, each increment represented 10 percent of stream width. A minimum increment width of 5 centimeters (cm) was used to estimate flow volume in drains less than 0.5 m wide. Water column depth (cm) at the center of each increment was assumed to represent the average increment depth. Water velocity (cm per second; cm/s), also measured at the center point of each increment, was measured at 60 percent of the water column depth with a Marsh McBirney model 401 Water Current Meter. This velocity represented mean velocity of that increment. At measurement sites where bottom sediments in drains would not support the wading rod, a strip of 0.64 cm (0.25 inch) plywood (approximately 15 cm X 30 cm) was used to support the rod. Flow velocities, increment width, and water column depth were used to calculate discharge for each increment. The sum of discharges for all transect increments represented instantaneous discharge at that transect. Reverse flows were found in three locations (2 sites in West Carson Lake Drain and one site in Carson Lake 1 Drain). To quantify dissolved solids movement at these sites the absolute value of these flows were used to determine loading rates.

Specific conductance (microsiemens/cm; μS/cm) was measured with a Yellow Springs Instruments Model 33 S-C-T Meter. Specific Conductance from this meter was periodically referenced with one of two Fisher Scientific Company Digital conductivity Meters to check accuracy. To calculate loading rates, specific conductance measurements were converted to TDS (milligrams per liter; mg/L) using the following relationships (Hoffman et al. 1990):

Specific conductance (SC) less than 5,000 μS/cm:

\[
\text{TDS (mg/L)} = 0.5B4(\text{SC}) + 22.1
\]

Specific conductance over 5,000 μS/cm:

\[
\text{TDS (mg/L)} = 0.682(\text{SC}) - 269
\]

Hoffman et al. (1990) cautioned against using the latter formula for extrapolating TDS at levels greater than 9,000 μS/cm. However, for comparative purposes, this formula was used to calculate loading rates at five sites (three in Harmon Drain HDS1 lateral, one in Carson Lake 1 Drain CLN1 lateral, and one in Carson Lake Drain COW3 lateral) where specific conductance exceeded 9,000 μS/cm. Instantaneous TOS loading rates (grams per second; g/s) were obtained by the following formula:

\[
\text{TOS loading rate (g/s)} = (\text{LJs})(\text{mgjL})j1000
\]
Discharge, specific conductance, and corresponding loading rates represent conditions at the time of sampling. Conditions vary widely depending on season and agricultural practices at the time of sampling. Comparisons of load estimates among drains in the Newlands Project were not attempted because of temporal variability. The absence of flow at many sites did not permit loading rate calculations.

Results and Discussion

A total of 347 sites representing over 300 km of drains were surveyed during this study (Appendix A presents site data; Appendix B illustrates the locations of sites). These sites were located in 21 drains, 14 of which discharged toward Stillwater WMA and 7 of which discharged toward Carson Lake (Fig. 2; Table 1). These drains branched into 187 lateral and sublateral drains. Conditions in major laterals and sublateral drains are summarized in Table 2.

Where possible, sites were established at locations where detritus samples were collected in 1988 as part of the detailed study. Results of trace element analyses for these samples are presented in Rowe et al. (1991). Concentrations of arsenic, boron, and selenium in S9 detritus samples collected from agricultural drains in the Carson Division of the Newlands Project are used to further characterize conditions in agricultural drains (Table 3).

Stillwater Wildlife Management Area Drainage

A total of 268 sites representing over 220 kilometers in 14 drains that discharge toward Stillwater WMA were surveyed (Table 1). Specific conductance of drain water ranged from 250 to >50,000 \( \mu \text{s/cm} \). Specific conductance at 123 sites in 9 primary drain systems where flowing water was found ranged from 290 to 16,000 \( \mu \text{s/cm} \). Discharge at these sites ranged from <1 to almost 1700 L/s. Loading rates ranged from <1 to over 630 g/s. Conditions in individual drains are discussed below.

Diagonal Drain

Diagonal Drain, extending almost 80 km, was the most extensive drain surveyed. This drain discharges to Stillwater Point Reservoir on Stillwater WMA (Appendix B). Specific conductance at 92 sites ranged from 350 to 3,020 \( \mu \text{s/cm} \) during the fall (Table 1). Sixty sites conveyed flowing water when surveyed. Specific conductance at these sites ranged from 350 to 2,400 \( \mu \text{s/cm} \). The maximum discharge, approximately 1,700 L/s, and the maximum TDS loading rate, approximately 630 gis, were found in the main stem near the terminus of the drain (Appendix A). No lateral appeared outstanding in terms of TDS load contribution. At flowing water sites higher specific conductance levels were found in laterals DDN4 (Pasture Road Drain), DDN5 (unnamed), and DDN8 (Harrigan Road Drain) and sublaterals DDN6W1 and DDN6W2 in Testolin Road Drain (Table 2). However, discharge and corresponding loading rates were generally low. Higher loading rates were found in laterals DDN2 (L Line Canal), DDN3 (Lower Diagonal Drain), and DDN6 (Testolin Road Drain). However, high loading rates were attributable to higher discharge levels.

Thirteen detritus samples were collected from Diagonal Drain during the detailed study (Rowe et al. 1991). Relatively high concentrations of arsenic and selenium were found in samples collected at survey site DD10 on the main stem (44 and 1.9 \( \mu \text{g/g} \), respectively) and site DDN6W33 in Testolin Road Drain (38 and 2.6 \( \mu \text{g/g} \), respectively; Table 3). A relatively high boron concentration (47 \( \mu \text{g/g} \)) was found at sample site DDN3.2 in Lower Diagonal Number 1 Drain. Concentrations of arsenic, boron, and selenium in detritus at
other collection points in this drain were below or slightly above mean levels in the project area.

New River Drain

New River Drain, surveyed during the fall, discharges to Harmon Reservoir, a Newlands Project reregulating reservoir. Water in the reservoir is used to irrigate agricultural fields near Stillwater NWR. Specific conductance at 26 sites in New River Drain, including 11 flowing water sites, ranged from 290 to 2250 µS/cm (Table 1). The maximum discharge, over 140 L/s, and the maximum loading rate, almost 60 gis, were found in the main stem above site NR6. Below this point, drain discharge was pumped into L Line Canal, a Newlands Project water delivery canal. Four of 8 laterals contained flowing water (Table 2). Higher specific conductance levels were found in laterals NRN1 and NRS3. However, discharge and corresponding loading rates were relatively low.

Two detritus samples were collected from New River Drain during the detailed study (Rowe et al. 1991). One sample collected in the main stem near site NR5 contained a comparatively high concentration of arsenic (54 µg/g) and a moderate concentration of boron (44 µg/g; Table 3).

South Harmon Drain

South Harmon Drain enters Harmon Reservoir on the southern end. Two sites representing 3.3 km of drain were sampled during the fall. Specific conductance was 530 and 850 µS/cm (Table 1). Flowing water was found at site HS1 (Table 2). A loading rate of approximately 15 g/s was estimated from a flow of approximately 30 L/s.

One detritus sample collected near the mouth of South Harmon Reservoir Drain during the detailed study (Rowe et al. 1991) contained comparatively low concentrations of arsenic, boron, and selenium (Table 3).

North Harmon Drain

North Harmon Drain enters Harmon Reservoir at the north-western end. Two sites representing 1.5 km were sampled during the fall. Specific conductance was 720 and 1,290 µS/cm (Table 1). Low discharge at each site corresponded to low loading rates (Table 2). Rowe et al. (1991) did not collect detritus samples for trace element analysis from this drain.

Harmon Drain

Harmon Drain, surveyed during the fall, discharges to Stillwater Slough. Stillwater Slough enters Stillwater NWR near Lead Lake. Thirty-eight sites, representing over 25 km, were surveyed in this drain. Specific conductance ranged from 250 to 16,000 µS/cm (Table 1). Specific conductance at 24 flowing water sites ranged from 320 to 16,000 µS/cm. The maximum discharge rate, 85 L/s, and loading rate, over 75 gis, were found in the main stem of the drain. In laterals with flowing water, the highest specific conductance (16,000 µS/cm) was found in the 4.2 km-10ng HD81 lateral (Table 2). This value exceeded the 9,000 µS/cm range for conversion of specific conductance to dissolved solids (mg/L) presented in Hoffman (1990), so accurate conversion was not possible. However, for comparative purposes, a loading rate of over 60 g/s for a discharge of 7 L/s is obtained if Hoffman's conversion formula is used. Relatively high specific conductance values were also found in lateral HDN1. However, a low discharge «1 L/S) corresponded to a relatively low loading rate (1.4 g/S) in this 1.4 km-10ng lateral. Above the confluence of
these laterals, specific conductance drops considerably. The maximum specific conductance value observed in the remainder of the drain was 1,000 \( \mu S/cm \).

Five detritus samples were collected from Harmon Drain during the detailed study (Rowe et al. 1991). Relatively high arsenic concentrations were found at sites HD6 and HDSS (74 and 41 \( \mu g/g \), respectively), a high boron concentration was found at site HDS1.2 (53 \( \mu g/g \)), and a high selenium concentration was found at site HDS5 (2.4 \( \mu g/g \); Table 3).

Kent Drain East

Kent Drain East, surveyed during the summer, also discharges to Stillwater Slough. Specific conductance at a site on this short (1 km) drain was 1450 \( \mu S/cm \) (Table 1). Flowing water was not found in this drain, therefore a loading rate was not determined. Rowe et al. (1991) did not collect detritus samples for trace element analysis from this drain.

Kent Drain

Kent Drain, which discharges to Stillwater Slough, was surveyed during the summer. Specific conductance at 4 sites ranged from 3,500 \( \mu S/cm \) to greater than the capacity of our meter (>50,000 \( \mu S/cm \)). No flowing water was found in this drain. Evaporation, and subsequent concentration of dissolved solids at these stagnant sites, undoubtedly contributed to these extreme TDS concentrations. The lack of flowing water prohibited the determination of loading rates in this drain. However, high TDS concentrations suggest that load contributions from this drain may be significant under higher flow conditions. Rowe et al. (1991) did not collect detritus samples for trace element analysis from this drain.

Norton Drain

Six sites in Norton Drain, which also discharges to Stillwater Slough, were surveyed during the summer. Specific conductance ranged from 8,000 \( \mu S/cm \) to greater than the capacity of our equipment (>50,000 \( \mu S/cm \)). Again, concentration of dissolved solids through evaporation at these stagnant sites undoubtedly contributed to these extreme TDS concentrations. Again, loading rates in this drain were not determined, but high TDS concentrations suggest that load contributions from this drain may be significant under higher flow conditions. Rowe et al. (1991) did not collect detritus samples for trace element analysis from this drain.

Paiute Diversion Drain

Paiute Diversion Drain, surveyed during the summer, enters Stillwater NWR near Lead Lake. Specific conductance at 42 sites, representing over 40 km, ranged from 300 to 39,500 \( \mu S/cm \) (Table 1). Specific conductance at 11 flowing water sites ranged from 410 to 1,700 \( \mu S/cm \). The maximum loading rate, almost 45 gis, was found in the main stem (Table 2). Flowing water was found in only 3 of 11 laterals. Specific conductance in these laterals was relatively low. Like Kent and Norton Drains, evaporation undoubtedly contributed to concentration of dissolved solids leading to high specific conductance values in laterals with stagnant water.

Concentrations of arsenic, boron, and selenium were comparatively low in six detritus samples collected from Paiute Diversion Drain during the detailed study (Rowe et al. 1991).
Paiute Drain

Paiute Drain, surveyed during the summer, enters Stillwater NWR near Lead Lake. Specific conductance at 32 sites, representing almost 25 km of drain, ranged from 400 to 8,900 μS/cm (Table 1). Specific conductance at 9 flowing water sites ranged from 400 to 1,830 μS/cm. Flowing water was found in 3 of 7 laterals. The maximum discharge, approximately 150 L/s, and the maximum loading rate, over 90 g/s, was found near the terminus of lateral PDWI (Table 2). Specific conductance was relatively high in Bailey Drain (lateral PDSI), but the discharge and corresponding loading rate were relatively low. Concentrations of arsenic, boron, and selenium were comparatively low in three detritus samples collected from Paiute Drain during the detailed study (Rowe et al. 1991).

Shaffner Drain

Shaffner Drain discharges to Vaughn Slough near the Indian Lakes area on Stillwater WMA. Seven sites, representing 2.7 km, were surveyed during the summer. Specific conductance ranged from 1,550 to 2,100 μS/cm (Table 1). Flowing water was only found at one site in the main stem. A flow of 12 L/S and a specific conductance level of 1650 μS/cm corresponded to a loading rate of approximately 11 g/s (Table 2).

Two detritus samples were collected from Shaffner Drain during the detailed study (Rowe et al. 1991). Selenium concentrations in these samples were among the highest observed during that study (3.2 and 6.5 μg/g; Table 3). One sample also contained a relatively high concentration of boron (74 μg/g).

ERB Drain

ERB Drain discharges to the Carson River near Sagouspi Dam. Nine sites representing 11 km of drain were surveyed during the summer. Specific conductance ranged from 480 to 2,000 μS/cm (Table 1). Specific conductance at 4 flowing water sites in the main stem ranged from 1,500 to 1,600 μS/cm. Modest flows at these sites corresponded to relatively large loading rates (Table 2). No flowing water was found in 3 laterals.

One detritus sample collected from ERB Drain during the detailed study (Rowe et al. 1991) contained a comparatively high concentration of arsenic (46 μg/g; Table 3).

Lower Soda Lake Drain

Lower Soda Lake Drain discharges to the Carson River upstream of sagouspi Dam. Five sites representing 3.3 km were surveyed during the summer (Table 1). Specific conductance ranged from 1,100 to 1,520 μS/cm. Flowing water was not found at any sites surveyed. Rowe et al. (1991) did not collect detritus samples for trace element analysis from this drain.

Upper Soda Lake Drain

Upper Soda Lake Drain discharges to the Carson River upstream of Sagouspi Dam. Two sites representing 3.8 km were surveyed during the Summer (Table 1). Specific conductance at these sites were 1,220 and 1,700 μS/cm. Flowing water was not found at either site.

One detritus sample collected from Upper Soda Lake Drain during the detailed study (Rowe et al. 1991) contained comparatively high arsenic and selenium concentrations (44 and 3.0 μg/g, respectively; Table 3).
Carson Lake Area Drainage

Over 90 km in seven drains were surveyed in the Carson Lake drainage area during the summer (Table 1). With the exception of Carson Lake Drain and Downs Drain, all drains discharge to Lee Drain, which serves as a water distribution canal for Carson Lake Pasture. Specific conductance at 79 sites, including 39 sites where flowing water was found, ranged from 350 to 13,500 μS/cm. Discharge at the sites ranged from <1 to almost 430 Lis. Loading rates ranged from approximately 2 to over 220 g/s. Conditions in individual drains are discussed below.

West Carson Lake Drain

Specific conductance at 3 sites in West Carson Lake Drain, including 2 where flowing water was found, ranged from 2,100 to 4,500 μS/cm (Table 1). Discharge and loading rates at each site were relatively low (Table 2). Rowe et al. (1991) did not collect detritus samples for trace element analysis from West Carson Lake Drain.

Carson Lake 1 Drain

Specific conductance at 25 sites in Carson Lake 1 Drain, including 13 sites where flowing water was found, ranged from 400 to 13,500 μS/cm (Table 1). The maximum discharge, almost 100 Lis, and maximum loading rate, over 60 gis, were found in the main stem of the drain (Table 2). Flowing water was found in 5 of 9 laterals. Higher specific conductances and higher loading rates were found in laterals CL11 and CLW1. Lateral CL11 was particularly notable. Unfortunately, specific conductance in this lateral, 13,500 μS/cm, exceeded the 9,000 μS/cm range for conversion of specific conductance to dissolved solids (mg/L) presented in Hoffman (1990), so accurate conversion to TDS was not possible. However, for comparative purposes, a loading rate of over 22.2 gis for a discharge of 2.5 Lis is obtained if Hoffman's conversion formula is used.

Six detritus samples were collected from Carson Lake 1 Drain during the detailed study (Rowe et al. 1991). With the exception of a moderate concentration of arsenic in a sample from lateral CLW5 (37 μg/g) and a moderate concentration of boron in a sample collected near site CL7 (41 μg/g), concentrations of arsenic, boron, and selenium were generally below or only slightly above mean concentrations of samples collected throughout the Newlands Project area (Table 3).

Carson Lake Drain

Specific conductance at 23 sites in Carson Lake Drain, including 12 sites where flowing water was found, ranged from 700 to 11,200 μS/cm (Table 1). The maximum discharge, almost 90 Lis, and maximum loading rate, almost 110 gis, were found in the main stem of the drain (Table 2). The higher loading rates were found near the drain terminus. Flowing water was found in 4 of 7 laterals. Specific conductances and loading rates were moderately high in laterals CDW1, CDW3, and CDW4. Specific conductance at two sites in lateral CDW3 exceeded the 9,000 μS/cm range for conversion of specific conductance to dissolved solids (mg/L) presented in Hoffman et al. (1990), so accurate conversion to TDS was not possible. However, for comparative purposes, a loading rate of over 3.1 gis for a discharge of 0.4 Lis is obtained if Hoffman's conversion formula is used.

Four detritus samples were collected from Carson Lake Drain during the detailed study (Rowe et al. 1991). The concentration of boron in a sample from lateral CDW3 was very high (100 μg/g) (Table 3). With the exception of a moderately high arsenic concentration in a sample collected near site CD7 (44
Concentrations of arsenic, boron, and selenium were generally below or only slightly above mean concentrations of samples collected throughout the Newlands Project area (Table 3).

Downs Drain

Specific conductance at 5 sites in Downs Drain, representing 4.3 km, ranged from 1,450 to 8,000 $\mu$S/cm (Table 1). Flowing water was only found in the main stem near the terminus of this drain (Table 2). A flow of approximately 8 L/s and a specific conductance of 1,450 $\mu$S/cm corresponded to a loading rate of more than 7 g/s.

One detritus sample collected from Downs Drain during the detailed study (Rowe et al. 1991) contained a high boron concentration (54 $\mu$g/g) and a very high selenium concentration (3.5 $\mu$g/g, Table 3).

Gummow Drain

Specific conductance at 3 sites in Gummow Drain, representing 6.7 km, ranged from 350 to 1,340 $\mu$S/cm (Table 1). Specific conductances at 2 flowing water sites were 350 and 600 $\mu$S/cm. The maximum discharge, 56 L/s, and maximum loading rate, 20.8 g/s, were found in the main stem of the drain.

Concentrations of arsenic, boron, and selenium in one detritus sample collected from Gummow Drain during the detailed study (Rowe et al. 1991) were near mean levels found in the Project area (Table 3).

L Drain

Specific conductance at 11 sites in L Drain, representing almost 15 km, ranged from 800 to 1,500 $\mu$S/cm (Table 1). Flowing water was only found in the main stem of the drain. Specific conductance at these 6 sites ranged from 800 to 900 $\mu$S/cm (Table 2). The maximum flow, approximately 260 L/s, corresponded to the maximum loading rate, almost 130 g/s.

Two detritus samples collected from L Drain during the detailed study (Rowe et al. 1991) contained concentrations of arsenic, boron, and selenium that were below mean levels found in the Project area (Table 3).

Lee Drain

Lee Drain serves as a water distribution canal for Carson Lake Pasture and receives drainwater from all drains flowing into the Carson Lake area. Specific conductance at nine sites in this drain ranged from 750 to 8,200 $\mu$S/cm (Table 1). Specific conductance at 3 flowing water sites ranged from 790 to 850 $\mu$S/cm.

Concentrations of arsenic, boron, and selenium in one detritus sample collected from Lee Drain during the detailed study (Rowe et al. 1991) were below mean levels found in the Project area (Table 3).

Conclusion

Specific conductance, discharge, and corresponding TDS loading rates in agricultural drains in the Carson Division of the Newlands Project were highly variable. Of drains that discharged to Stillwater Wildlife Management Area, Diagonal Drain had the highest loading rate. However, this drain also served the largest area and had the greatest discharge. Loading rates in other drains serving this area were considerably lower. Excluding Lee Drain, the largest loading rates entering Carson Lake were found in Carson Lake Drain and L Drain. Variability within and among drains reflect the dynamic nature of
the system. Conditions in drains are also highly variable. Lico (1992) found considerable changes in discharge and specific conductance in agricultural drains in relatively short periods of time. In extreme cases, specific conductance changed by more than 1,000 μS/cm in a 24 h period. Hoffman et al. (1990) found more gradual changes in specific conductance throughout the irrigation season; specific conductance was generally higher in the pre-irrigation season (late winter) and decreased in the late-irrigation season (fall). Long-term hydrologic conditions (drought) at the time of our study also affected observed conditions.

**Recommendations**

Several changes in study design are needed to more accurately assess agriculturally-induced contaminant contributions from specific areas in the Newlands Project. Most importantly, each sampling site should be monitored several times before, during, and following the irrigation season. More than one irrigation season may be needed to fully characterize discharge and accurately assess contaminant load contributions. Drain discharge should be correlated to irrigation water delivery to specific agricultural lands. Such a correlation should include amounts of water delivered and specific conductance of that water. Future studies should also integrate soils information such as overall soil types, alkalinity, and levels of salts and trace elements. Such information for Lahontan Valley is currently being developed by the Soil Conservation Service and the Bureau of Reclamation. To more fully characterize agricultural contaminants in specific drains, trace element analysis should accompany load allocations. This measure would allow assessment of relative contributions of specific trace elements.

Discharge measurements are also a source of error in determining contaminant loading rates. Where possible, existing water control structures should be used. However, few such structures occur in agricultural drains so fixed water control structures should be installed. Such structures may consist of V-notch weirs constructed of plywood.

Finally, because of the extent of the drainage system, future studies should focus on limited areas. Our data and those of Rowe et al. (1991) indicate several areas appear to contribute proportionally greater amounts of agricultural contaminants. Unfortunately, survey methodology and hydrologic conditions at the time of our sampling prevented meaningful load allocations to many of the drains and laterals. However, relatively high loading rates proportional to discharge were found in some drain laterals. These included:

- Harmon Drain laterals HDS1 and HDN1;
- Paiute Drain lateral PDS1;
- Carson Lake 1 Drain laterals CLN1 and CLW1;
- Carson Lake Drain laterals COW1, CDW3, and CDW4, and
- Downs Drain.

High specific conductance was found in other drains. However, no flowing water was found and loading rates could not be determined. Large loads of dissolved solids may be contributed under higher flow conditions. More data is needed to better assess loading rates from these drains.

Relatively high specific conductance was also found at two sample sites in Lee Drain. However, this drain served as a distribution canal for Carson Lake Pasture and probably received minimal subsurface drainage. High specific conductance probably reflects drainage from other agricultural drains (the Down's Drain discharge point is located near these sampling sites).

Analytical data for detrital matter collected from agricultural drains in the Carson Division of the Newlands Project from Rowe et al. (1991) also indicated that certain drains may contribute proportionally greater amounts of arsenic, boron, and selenium. Relatively high levels of these trace elements were found at one or more sites in the following drains and laterals:
Arsenic:
- Diagonal Drain main stem and lateral DDN6W3,
  New River Drain main stem,
  Harmon Drain main stem and lateral HOSS,
  ERB Drain main stem,
  Upper Soda Lake Drain main stem,
  Carson Lake 1 Drain lateral CLWS,
  Carson Lake Drain main stem,

Boron:
- Diagonal Drain lateral DDN3,
  New River Drain main stem,
  Harmon Drain lateral HDS1,
  Shaffner Drain lateral SHS1,
  Carson Lake 1 Drain main stem,
  Carson Lake Drain lateral CDW3,
  Downs Drain main stem,

Selenium:
- Diagonal Drain main stem and lateral DDN6W3,
  Harmon Drain lateral HDSS,
  Shaffner Drain main stem and lateral SHS1,
  Upper Soda Lake Drain main stem,
  Downs Drain main stem.

Acknowledgements

This manuscript was improved by the critical reviews of Geoffrey A. Ekechukwu, Robert J. Hallock, Ray J. Hoffman, Stephen B. Moore, Fred L. Paveglio, and Stanley N. Wiemeyer. Craig Stockwell assisted in much of the field work. Joe Maez assisted with preparation of graphics.
References


Table 1. Number of sample sites, drain lengths, and specific conductance (mean and range) of all sites, and number of sites, discharge range (liters per second), specific conductance (mean and range), and TOS loading rate (grams per second) for selected agricultural drains in the Carson Division of the Newlands Project that discharge toward Stillwater National Wildlife Refuge (NWR) and Carson Lake. Data were collected during the fall, 1990, and summer, 1991.

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NA - Specific conductance exceeded the range of the meter. Calculations of means were not possible.
Table 2. Number of sample sites, drain lengths, and specific conductance (mean and range) of all sites, and number of sites, discharge range (liters per second), specific conductance (mean and range), and TDS loading rate (grams per second) for the main stem, laterals, and sublaterals of agricultural drains discharging toward Stillwater National Wildlife Refuge and Carson Lake. Data were collected in the fall, 1990, and summer, 1991.

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Specific conductance exceeded the 9,000 uS/cm range for conversion of specific conductance to total dissolved solids (mg/l) given in Hoffman et al. (1990). Value given is, therefore, an approximation.
Table 3. Concentrations (µg/g dry weight) of arsenic, boron, and selenium in detritus samples collected from agricultural drains near Fallon, Nevada during a Department of the Interior study of agricultural drainage in the Newlands Project. Data is from Rowe et al. (1991).

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Figure 1. Map of Carson and Truckee River drainages showing the Newlands Project, Stillwater Wildlife Management Area and National Wildlife Refuge, and Carson Lake.
Figure 2. Map showing major drains of the Newlands Project.
APPENDIX A
Table A1. Physical data and total dissolved solids load estimates for agricultural drainage systems in the Carson Division of the Newlands Project in Churchill County, Nevada, that discharges to St. John's National Wildlife Refuge and Management Area.

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### APPENDIX A

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### Table A2: Physical data and total dissolved solids load estimates for agricultural drainage systems in the Carson Division of the Newlands Project in Churchill County, Nevada that discharge to Carson Lake.

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<th>Segment Length (mL)</th>
<th>Temp. (C)</th>
<th>Specific Cond. (ppl)</th>
<th>TDS (mg/l)</th>
<th>Salinity (umhos)</th>
<th>Flow (cts)</th>
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## APPENDIX A

### Table A2. (Continued)

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<td>TDs (mg/l)</td>
<td>Salinity (ppt)</td>
<td>Aow (cis)</td>
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Figure B1. US Geological Survey 7.5 minute quadrangles corresponding to sections. Drains found in each section are illustrated on the following maps.
Figure B2. Sampling sites on agricultural drains in section 2 of the USGS Soda Lake East 7.5 minute quadrangle. Total dissolved solids concentrations are given in parentheses.
Figure 83. Sampling sites on agricultural drains in section 2 of the Indian Lakes 7.5 minute quadrangle. Total dissolved solids concentrations are given in parentheses.
Figure 84. Sampling sites on agricultural drains in section 3 of the Indian Lakes 7.5 minute quadrangle. Total dissolved solids concentrations are given in parentheses.
Figure 85. Sampling sites on agricultural drains in section 1 of the USGS Stillwater 7.5 minute quadrangle. Total dissolved solids concentrations are given in parentheses.
Figure 86. Sampling sites on agricultural drains in section 2 of the Stillwater 7.5 minute quadrangle. Total dissolved solids concentrations are given in parentheses.
Figure 87. Sampling sites on agricultural drains in section 3 of the USGS Stillwater 7.5 minute quadrangle. Total dissolved solids concentrations are given in parentheses.
Figure 88. Sampling sites on agricultural drains in section 4 of the USGS Stillwater 7.5 minute quadrangle. Total dissolved solids concentrations are given in parentheses.
Figure 89. Sampling sites on agricultural drains in section 1 of the USGS Fallon 7.5 minute quadrangle. Total dissolved solids concentrations are given in parentheses.
Figure 810. Sampling sites on agricultural drains in section 2 of the USGS Fallon 7.5 minute quadrangle. Total dissolved solids concentrations are given in parentheses.
Figure 811. Sampling on agricultural drains in section 4 of the USGS Fallon 7.5 minute quadrangle. Total dissolved solids concentrations are given in parentheses.
Figure 812. Sampling sites on agricultural drains in section 6 of the USGS Fallon 7.5 minute quadrangle. Total dissolved solids concentrations are given in parentheses.
Figure 813. Sampling on drains in section 7 of the USGS Fallon 7.5 minute quadrangle. Total dissolved solids concentrations are given in parentheses.
Figure 814. Sampling sites on agricultural drains in section 1 of the USGS Grimes Point 7.5 minute quadrangle. Total dissolved solids concentrations are given in parentheses.
Figure 815. Sampling sites on agricultural drains in section 2 of the USGS Grimes Point 7.5 minute quadrangle. Total dissolved solids concentrations are given in parentheses.
Figure 816. Sampling sites on agricultural drains in section 3 of the USGS Grimes Point 7.5 minute quadrangle. Total dissolved solids concentrations are given in parentheses.
Figure 817. Sampling stations on agricultural drains in section 4 of the USGS Grimes Point 7.5 minute quadrangle. Total dissolved solids concentrations are given in parentheses.
Figure 818. Sampling sites on agricultural drains in section 5 of the USGS Grimes Point 7.5 minute quadrangle. Total dissolved solids concentrations are given in parentheses.
Figure 619. Sampling on drains in section 6 of the USGS Grimes Point 7.5 minute quadrangle. Total dissolved solids concentrations are given in parentheses.
Figure 820. Sampling stations on agricultural drains in section 7 of the USGS Grimes Point 7.5 minute quadrangle. Total dissolved solids concentrations are given in parentheses.
Figure 821. Sampling on agricultural drains in section 8 of the USGS Grimes Point 7.5 minute quadrangle. Total dissolved solids concentrations are given in parentheses.
Figure 822. Sampling sites on agricultural drains in section 7 of the Lahontan Mountains 7.5 minute quadrangle. Total dissolved solids concentrations are given in parentheses.
Figure 823. Sampling on drains in section 8 of the USGS Lahontan Mountain 7.5 minute quadrangle. Total dissolved solids concentrations are given in parentheses.
Figure 824. Sampling sites on agricultural drains in section 4 of the USGS South of Fallon 7.5 minute quadrangle. Total dissolved solids concentrations are given in parentheses.
Figure 825. Sampling on agricultural drains in section 6 of the USGS South of Fallon 7.5 minute quadrangle. Total dissolved solids concentrations are given in parentheses.
Figure 826. Sampling sites on agricultural drains in section 8 of the USGSouth of Fallon 7.5 minute quadrangle. Total dissolved solids concentrations are given in parentheses.
Figure 827. Sampling sites on agricultural drains in section 5 of the USGS Carsons Lake 7.5 minute quadrangle. Total dissolved solids concentrations are given in parentheses.
Figure 828. Sampling sites on agricultural drains in section 7 of the USGS Carson Lake 7.5 minute quadrangle. Total dissolved solids concentrations are given in parentheses.