THE WATER SOLUBLE NITROGEN AND PHOSPHORUS BALANCES FOR A LARGE IRRIGATION DISTRICT[1]

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Concern for the quality of man's environment has caused widespread speculation about how phorphorus and nitrogen fertilizers affect surface- and ground-water quality. Charges that phosphorus is the key to algal blooms and prolific aquatic plant growth and that NO_3-N in water is poisoning our livestock, stimulating aquatic plant growth, and increasing the incidence of methemoglobinemia--commonly known as "blue baby"--have become widespread (9, 11, 13, 16, 17, 18). The critical PO_4-P concentration in water required to support algal blooms has been reported to range from 0.02 to 0.05 ppm (9, 11, 13, 16, 18). Kuentzel (6) has recently suggested that carbon is more likely the key to algal blooms, than is phorphorus. He points out that phosphorus is needed for algal growth and reproduction, but that concentrations below 0.01 ppm are sufficient for algal blooms provided other factors are present in adequate amounts. Nevertheless, it is popular opinion that phosphorus is the key to algal blooms and that much of the phosphorus in our surface water is derived from the application of phosphorus fertilizers.

Phosphorus compounds in the soil are so insoluble that percolating waters carry away little or no PO_4-P (2, 8, 17). Generally, concentrations in subsurface drainage water are 0.03 ppm PO_4-P or less. Concentrations found in subsurface drainage water from a California irrigation project were below 0.03 ppm, and the researchers concluded that insignificant amounts of the phosphorus applied to the soil were removed by tile drainage water. More field information is needed to ascertain the overall effects of irrigation and phosphorus fertilization in a cropped area on the PO_4-P load of irrigation return flows. Such information is needed to determine the necessity to change irrigation practices to reduce PO_4-P loads and for use in designing new irrigation projects.

Investigations in California and Washington concluded that much of the applied nitrogen fertilizer passed through the soil into the subsurface drainage water (5, 15). In contrast, a study conducted on the upper Rio Grande River indicated that the increased use of nitrogen fertilizer during the past 30 years has not increased the NO_3-N concentration in the River (1). Information is needed on more field projects, particularly where both inputs and outputs can be measured, to properly assess the importance of NO_3-N loads in irrigation return flows.

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[1] Proceedings, Twenty-first annual Fertilizer Conference of the Pacific Northwest, Salt Lake City, Utah, July 14-16, 1970.

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This paper reports results of an investigation conducted in southern Idaho on the water-soluble PO_4-P and NO_3-N balances for a 202,702-acre irrigation tract. The inputs of PO_4-P and NO_3-N in the irrigation water and the outputs in drainage waters were determined.

METHODS AND PROCEDURES

The study area is a semi-desert having approximately 8.5 inches of precipitation annually. The Twin Falls Canal Company, a private company, developed the 202,702-acre tract and began diverting water at Milner Dam for irrigation about 1905 (Figure 1). Water is distributed by gravity flow and delivered to farmers in a continuous small stream basis of 0.5 cfs/40 acres. Surface runoff water from fields generally returns to the canal system. Water is in the canal system from about April 1 to November 15 each year. The area is bordered on the north by the Snake River, which is in a canyon about 500 ft deep. All surface and subsurface drainage flows into the Snake River.

Soils in the area are primarily wind-deposited, calcareous, silt loams, ranging from 0 to about 50 feet deep. Lime- and silica-cemented hardpan layers occur at depth from 12 to 18 inches throughout the area. The soils are underlain by fractured basalt several hundred feet deep. All crops grown are irrigated by small furrows, and infiltration rates are relatively high.

The most important crops grown in the area are alfalfa, dry beans, sugarbeets, small grain, corn and pasture (Table 1). Seeding dates vary from about April 1 to as late as June 15. Harvesting is generally completed by late October.

Soon after irrigation was begun, localized high water tables developed. To correct these problems the Canal Company excavated tunnels 4 feet wide by 7 feet high horizontally into the basalt beneath the high water table areas. Excavation was terminated whenever a fracture in the basalt was intercepted that conveyed significant amounts of water. The tunnels conveyed subsurface water by gravity flow to a natural surface drain. Tunnel lengths ranged from 0.25 to 1.5 miles. This practice was satisfactory for alleviating high water table conditions. However, tunneling was replaced by installing less expensive tile-relief well networks during the 1930's. Relief wells 30 to 70 feet deep were drilled on a network in a high water table area and the well tops were connected by tile lines 3.5 to 10 feet below the soil surface. The wells flow from hydrostatic pressure, and the effluent is conveyed through the tile lines to a natural surface drain. This technique proved effective and is used today.

Fifteen tunnel and five tile-relief well network outlets were selected for sampling subsurface drainage water in the subject area. Surface runoff samples were collected from natural surface drains. Irrigation water was sampled at the Milner Dam diversion (Figure 1). Samples were collected at 2-week intervals and analyzed for water-soluble NO_3-N (12) and PO_4-P (19). Samples collected at selected dates were also analyzed for soluble polyphosphates (14) and NH_4-N and NO_2-N by microdiffusion.

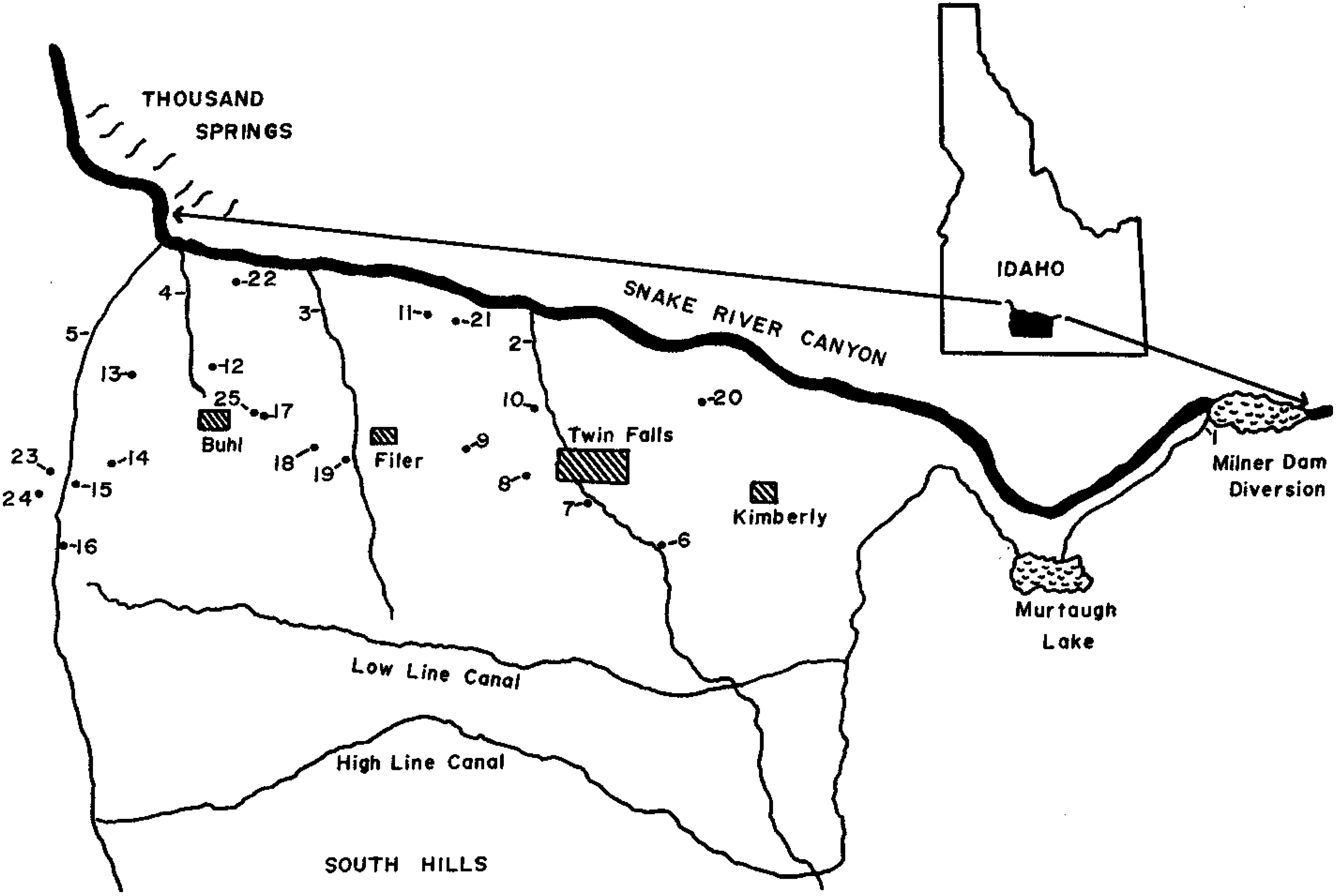

Fig. 1. The study area illustrating sampling sites and important features.

Table 1. Computed evapotranspiration and estimated amounts of nitrogen and phosphorus fertilizers applied yearly for the crops grown on the Twin Falls Canal Company tract.

Crop	Acres	Evapotranspiration Year	Evapotranspiration Crop Season	Fertilizer Applied* N	Fertilizer Applied* P	Fertilizer Applied* P_2O_5
		inches	inches	lb/A	lb/A	lb/A
Alfalfa	37,811	41.5	39.1	0	44	100
Dry beans	35,333	24.8	19.6	30	22	50
Spring grain	24,302	23.0	18.9	55	18	40
Irrigated pasture	21,623	42.2	40.1	95	9	20
Sugar beets	21,069	32.6	30.0	145	57	130
Corn	15,765	27.8	23.5	110	26	60
Fall grain	8,100	24.1	19.6	100	20	45
Potatoes	3,997	29.9	26.3	150	62	140
Peas	2,130	24.3	20.3	35	31	70
Towns, canals, etc	20,000	42.2	40.1	--	--	--
Nonirrigated area	12,572	7.7	7.7	--	--	--
Total	202,702	--	--	--	--	--
Weighted mean	--	31.3	--	53	27	58

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*Phosphorus applied is given in both lbs of P and P_2O_5 for convenience. Several different source materials were used.

The water balance for the tract was based on the following equation (3):

$$D + P = ET + G + Q \pm \Delta S$$

Where:

D = all water diverted into the tract.
P = precipitation.
ET = evapotranspiration.
G = Subsurface drainage or deep percolation.
Q = surface runoff.
ΔS = change in soil water content.

The quantity of water diverted, D, was measured by the Canal Company and the U. S. Geological Survey. Precipitation, P, was measured by the U. S. Weather Bureau. ET was computed for each crop (Table 1) by techniques applicable to the area (4, 10). Surface runoff, Q, was measured with weirs, flumes and current meters. Hydrograph separation techniques were applied where necessary (7). The change in soil water content, ΔS, was considered negligible because the water content in the soil is about the same at the beginning of each water year. The quantity of subsurface drainage, G, was obtained by difference. Nevertheless more than half of it was measured at tunnel and tile-relief well network outlets by weirs, flumes and current meters.

The quantities of nitrogen and phosphorus fertilizers applied (Table 1) were estimated based on the amounts sold by fertilizer dealers in the area.

RESULTS AND DISCUSSION

The water balance indicated that 50% of the total input water became subsurface drainage (Table 2). ET amounted to 36% of the total input. The remaining 14% was surface runoff. Excessive leaching is occurring under the present water management practice. This excessive leaching removes more soluble salts than necessary for maintaining a salt balance. It also increases the probability of NO_3-N being leached from the soil.

Table 2. Water balance for the 202,702-acre Twin Falls Canal Company irrigation tract for the water year October 1, 1968 through September 30, 1969.

	Acre Feet	%
Input		
Diverted from Snake River	1,290,000	89
Runoff from South Hills	32,000	2
Precipitation, (7.7 inches)	103,100	9
City of Twin Falls	900	0
Total	1,453,000	100
Output		
Evapotranspiration, (31 inches)	523,650	36
Surface runoff	203,880	14
Subsurface drainage	725,470	50
	1,453,000	100

Snake River water diverted at Milner Dam contained an average PO_4-P concentration of 0.066 ppm (Table 3), but the concentrations ranged from 0.015 to 0.148 ppm. Concentrations were lowest in June and July, during and immediately following peak flow in the River from snowmelt. The PO_4-P input (Table 4) was computed from monthly mean PO_4-P concentrations and monthly water diversions because of considerable variation in PO_4-P concentration over the year. Using the mean monthly data gave 93 tons PO_4-P input, but using the yearly mean concentration of 0.066 ppm and the yearly water diversion gave a higher input of 105 tons. Snake River water contains some organic load, which probably contains some organic-P, and occasionally some polyphosphates were found in the River water. In contrast, the effluent subsurface drainage waters are essentially free of organic matter and contain no detectable amounts of polyphosphates. Therefore, the PO_4-P balance presented has relatively low inputs compared to a balance of total-P. Even so, only 30% as much PO_4-P left the tract via the drainage water as entered it via the irrigation water. Thus irrigation decreased the PO_4-P (and total P) load in the River downstream from the tract. Furthermore, there was no evidence that any of the 27 lbs of P (58 lbs P_2O_5) applied per acre per year as fertilizer leached into the drainage water. These results are not surprising considering the reactions and solubility of phosphorus compounds in the soil (2, 8). The PO_4-P concentration in surface runoff water was the same as it was in the irrigation water, indicating that phosphorus compounds are not dissolved into water that passes across the soil surface.

The mean NO_3-N concentration in the subsurface drainage water was 3.24 ppm compared with only 0.12 ppm in the irrigation water. The 3.24 ppm is relatively low compared with public health standards of 10 to 20 ppm as a maximum concentration allowable in drinking water. Concentration variations in the effluent drain waters were relatively small. The mean concentrations in both irrigation and drainage waters were used in computing a NO_3-N balance (Table 4). Surface runoff contained the same NO_3-N concentration found in the irrigation water.

Table 3. Mean concentrations of water soluble PO_4-P and NO_3-N in irrigation and effluent drainage waters of the Twin Falls Canal Company irrigation tract.

	Site No. Figure 1	PO_4-P	NO_3-N
Irrigation water		ppm	ppm
Snake River water	1	0.066	0.12
Surface runoff	2-5*	0.066	0.12
Drainage tunnels			
Claar	6	0.013	4.02
Fish Hatchery	7	.013	2.24
Grossman	8	.014	2.25
Nye	9	.009	2.44
Tolbert	10	.012	3.30
Walters	11	.008	3.47
Mendini	12	.009	3.97
Neyman	13	.011	3.40
Galloway	14	.014	3.58
Cox	15	.015	3.44
Herman	16	.017	3.00
Harvey	17	.008	3.39
Peavy	18	.007	3.02
Padget	19	.008	3.01
Hankins	20	.012	3.55
Tile-well complexes			
Brown	21	.009	3.01
Hutchinson	22	.012	3.20
Kaes	23	.023	3.40
Molander	24	.009	3.79
Harvey	25	.023	3.30
Mean, subsurface drainage water		0.012	3.24

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*Surface runoff samples were collected throughout the tract where surface water ran off from fields. The small natural surface drains are not shown, but were sampled adjacent to the Snake River canyon.

A net NO_3-N output of 3,016 tons is equivalent to 30 lbs per acre per year (Table 4). This amount contributes to the NO_3-N load downstream in the Snake River. There are several potential sources of the NO_3-N in the subsurface drainage water, but how much comes from each source is not known. One potential source is leaching of NO_3-N produced from nitrification following decomposition of plant residues--including plowed alfalfa stands. The tract contains nearly 38,000 acres of alfalfa, and usually about 1/3 of this amount is plowed under each year. Another potential source is the 53 lbs of nitrogen per acre applied as fertilizer each year. The excessive leaching under the present water management might leach some applied NO_3-N into the subsurface drainage water. A third likely source is farm-home septic systems. A fourth, and probably important potential source, is nitrification in semidesert soils. Generally, such soils brought under irrigation give up considerable NO_3-N via the drainage water. There may also be other sources.

Table 4. Water soluble PO_4-P and NO_3-N balances for the 202,702-acre Twin Falls Canal Company irrigation tract for the water year, October 1, 1968 through September 30, 1969.

	PO_4-P Tons	NO_3-N Tons
Inputs		
In diverted Snake River Water	93	210
Outputs		
In surface runoff	16	32
In subsurface drainage	12	3,194
Total output	28	3,226
Net input	65	--
Net output	--	3,016

Results from this investigation should be applicable in principle to much of the West where calcareous soils are irrigated. Variation in the NO_3-N and PO_4-P balances among irrigation districts will depend upon the water balance and the geology of the area.

In conclusion, irrigating calcareous soils in the West may contribute to the NO_3-N load in surface water downstream from the irrigation tract. However, NO_3-N concentrations in the drainage water are relatively low compared with allowable concentrations for domestic use. In contrast, irrigation decreases the PO_4-P load in downstream water, and applied phosphorus fertilizers are retained by the soil and are not leached into subsurface drainage water.

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