Reprinted from the *Soil Science Society of America Proceedings*
Volume 35, Number 2, March–April 1971
677 South Segoe Road, Madison, Wisconsin 53711 USA

/6 C

DIVISION S-6—SOIL AND WATER MANAGEMENT AND CONSERVATION

Water-soluble NO_3-Nitrogen, PO_4-Phosphorus, and Total Salt Balances on a Large Irrigation Tract[1]

D. L. CARTER, J. A. BONDURANT, AND C. W. ROBBINS[2]

ABSTRACT

Return flow from a 82,030-ha (202,700-acre) tract of calcareous silt loam soils irrigated with water diverted from the Snake River in southern Idaho increased the downstream total soluble salt and NO_3-N loads, but decreased the downstream PO_4-P load. Under the existing water management practice, 50% of the total input water returned to the Snake River as subsurface drainage. Net total soluble salt output was 2.4 metric tons/ha (1.0 English ton/acre) and, on the average, was considerably greater than necessary to maintain a salt balance. Net NO_3-N output was 33 kg/ha (30 lb/acre). Only about 30% as much PO_4-P left the tract via drainage water as entered the tract in irrigation water. As water passed through the soil, PO_4-P was removed by chemical reactions in the soil, thus decreasing the concentration in the subsurface drainage water and decreasing the downstream PO_4-P load. Applied P fertilizer was not leached into the drainage water.

Additional Key Words for Indexing: **pollution, nutrients in water, salt load, nutrient load, water balance, evapotranspiration (ET).**

THE GROWING concern for the quality of man's environment has directed much attention to water quality. Public interest in environmental quality has aroused speculation about the effects of irrigation and the application of fertilizers on the quality of surface and ground waters. The Environmental Pollution Panel of the President's Science Advisory Committee (14) recommended that high priority be given to investigations of the relative contribution of nutrients and total salts from various sources that enter our surface and ground waters. Other groups have recommended that the contribution of fertilizers to the concentration of nitrogen and phosphorus in surface and ground waters be determined under various management systems, climatic environments, and on representative soil types (11, 15, 19, 21, 22).

A pressing need in irrigation agriculture is the development and evaluation of procedures to improve the quality of irrigation return flows. The factors controlling this quality of return flows are the quantity and quality of diverted water, evapotranspiration for the irrigated area, the proportions of the water that return as surface and subsurface drainage, and direct contributions of quality-degrading components from industry, municipalities, etc. A certain amount of leaching is required for maintaining a salt balance for sustained productivity of any irrigation project (1, 11, 21, 24, 25), but excessive leaching may dissolve more soil minerals and remove more soluble salts than necessary for a salt balance. The relationships between the amount of water passing through the soil and the salt concentration in return flows have not been investigated sufficiently on many projects. These relationships must be investigated under present irrigation practices to provide basic information for use in determining practices to improve the quality of return flows and in planning new irrigation projects.

There is much speculation that increased use of P fertilizers has greatly increased the PO_4-P concentration in surface waters, and that this concentration increase is the key to algal blooms and stimulated growth of aquatic plants (11, 14, 15, 19, 21, 22). PO_4-P concentrations ranging from 0.02 to 0.05 ppm have been reported as minimal for supporting algal blooms. Certainly algae require phosphorus for growth and reproduction. Unfortunately, many writers have considered only phosphorus as the key to water pollution and have ignored other possible key factors. Recently Kuentzel (8) presented convincing evidence that C is more

[1] Contribution from the Northwest Branch, Soil & Water Conserv. Res. Div., ARS, USDA; Idaho Agr. Exp. Sta., cooperating. Received Aug. 20, 1970. Approved Dec. 29, 1970.
[2] Research Soil Scientist, Agricultural Engineer, and Soil Scientist, respectively, Snake River Conserv. Res. Center, Route 1, Box 186, Kimberly, Idaho 83341.

likely the key to algal blooms than is P. Certainly, more research is needed to definitely establish factors controlling algal blooms.

Information on the P concentration in irrigation return flows is extremely limited. Chemical reactions of P in the soil indicate that PO_4-P concentrations in subsurface drainage waters should be very low (3, 4, 10, 12, 21). These concentrations should not exceed the solubility of the various phosphorus compounds found in the soil. Johnston and others (7) reported that the amount of phosphorus removed from an irrigated area through the subsurface drainage water was insignificant. More field information is needed. If irrigation return flows contain insignificant PO_4-P concentrations, we need to know about it. If they contain important quantities, we need to change practices to decrease the PO_4-P outputs from irrigated lands.

The NO_3-N concentration in subsurface drainage waters from irrigation generally exceeds that in the irrigation water (21). Several investigators have concluded that much of the NO_3-N in subsurface drainage waters originated from applied N fertilizer (7, 18). In contrast, Bower and Wilcox (2) concluded that the use of N fertilizer on adjacent irrigated land has not increased the NO_3-N concentration in the upper Rio Grande River. More information is needed from other irrigation projects to validly assess the importance of NO_3-N in irrigation return flows.

This paper reports results of an investigation of the water-soluble salt, PO_4-P, and NO_3-N balances for a 82,030-ha (202,700-acre) irrigation tract in southern Idaho. Inputs and outputs of these constituents were determined under existing water management practices.

MATERIALS AND METHODS

The study area (Fig. 1) was developed by the Twin Falls Canal Co. and has been under irrigation for about 65 years. Water is diverted from the Snake River and allocated to farmers at the rate of approximately 14 liters/sec for each 16 ha (0.5 cubic feet/sec for each 40 acres) continuously. Water is in the canal system from about April 1 to November 15 each year. Canal-flows in the early spring and late fall are considerably lower than during the peak irrigation season of June, July, and August because some crops do not require early spring and late fall irrigation.

Soils of the study area are wind deposited, calcareous, silt loams, ranging from 0 to 15 m (0–50 feet) deep. A caliche and silica cemented hardpan layer is found from 0.30 to 0.45 m (12 to 18 in.) below the surface over most of the area. The soils are underlain by fractured basalt to depths of several hundred meters. Water infiltration rates are fairly high and most crops are irrigated by small furrows.

The most important crops are alfalfa (*Medicago sativa* L.), dry beans (*Phaseolus* spp), sugarbeets (*Beta vulgaris* L.), small grain, corn (*Zea mays* L.), and pasture (Table 1). The row crops are normally seeded in April and May, and normally the last crop harvested is sugarbeets, which is generally in October. Mean annual precipitation for the area is approximately 210 mm (8.5 in.).

High water tables appeared in localized areas throughout the tract soon after irrigation was initiated in 1905. To alleviate this problem, the Canal Company excavated tunnels 1.3 m wide by 2.3 m high (4 by 7 feet), into the basalt underlying the high water table areas. Tunnels were terminated when fractures in the basalt carrying significant amounts of water were intercepted. The tunnels then served effectively as drain-

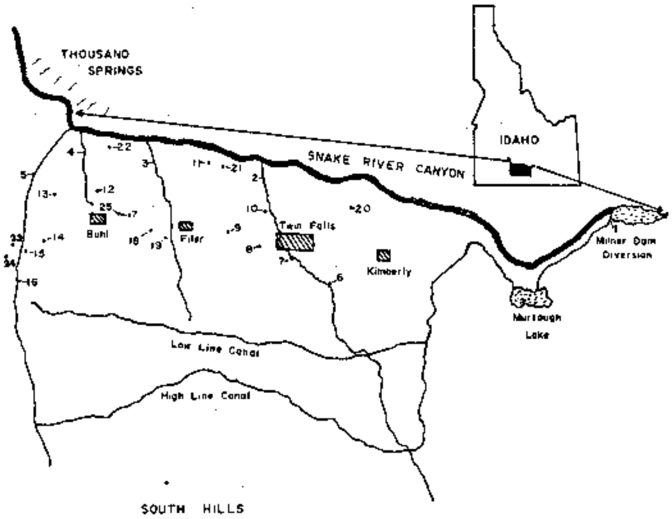

Fig. 1—The study area illustrating sampling sites and important features.

age channels to convey excess water into natural surface drains. Approximately 50 tunnels ranging from 400 to 2,400 m (0.25 to 1.5 miles) long were excavated before the practice was discontinued in the 1930's and replaced by relief wells connected by tile lines. These relief wells were 10 to 20 m (35 to 70 feet) deep, and the tile lines connecting them were 1 to 3 m (3.5 to 10 feet) below the ground surface. These wells flow from hydrostatic pressure, and water is conveyed to natural surface drains by the tile lines. This practice also has proved effective in lowering the water table and is still used today. Flow records for the drainage tunnels and tile-relief well networks, maintained by the Canal Company until the mid-1940's, were made available for review. All surface and subsurface drainage returns to the Snake River, which flows through a canyon 165 m (500 feet) deep, forming the northern boundary of the project.

Sampling sites selected throughout the area included the project diversion at Milner Dam on the Snake River, 15 drainage tunnel outlets, five tile-relief well network outlets, four main natural surface drains (Rock Creek, Cedar Draw, Mud Creek, and Deep Creek), and approximately 15 small natural surface drains returning water to the Snake River. These sites, except the small surface drains, are shown in Fig. 1 by number, and the numbers identify the data in Table 3. Samples from each site, except the 15 small natural surface drains, were collected at 2-week intervals for the Canal Company water year, October 1, 1968 through September 30, 1969. Surface runoff water samples were collected at irregular intervals during the study year. Weirs, flumes, and current meters were used to measure water flow at the sampling sites. The record of water diverted was provided by the Twin Falls Canal Co. in cooperation with US Geological Survey.

Water samples were analyzed for total soluble salt concentration and the usual salinity constituents (20), water-soluble PO_4-P (23) and water-soluble NO_3-N (20). In addition, some measurements were made of water-soluble polyphosphates by standard methods (16, 20) and of NH_4-N and NO_2-N by microdiffusion.

The total inputs and outputs of water-soluble salts, PO_4-P, and NO_3-N were based on the concentrations found in diverted waters, surface runoff water, and subsurface drainage water. To make these computations, it was necessary to compute a water balance for the system as described below. Total soluble salts, PO_4-P, and NO_3-N in the irrigation water were considered the primary inputs for the balance. The N input from precipitation was considered negligible in this study. Applied fertilizers were considered as factors affecting PO_4-P and NO_3-N outputs. Amounts of fertilizers applied were estimated by interviewing major fertilizer dealers in the area. Estimated yearly application rates for P and N, respectively, were 30 and 60 kg/ha (27 and 53 lb/acre).

A water balance based upon the following equation (5), was computed for the irrigation district:

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

where:

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

Most of the diverted water, D, was measured at the Milner Dam diversion. The contribution from the South Hills watershed was estimated from US Geological Survey records, and the small contribution from the city of Twin Falls was estimated from city records. Evapotranspiration, ET, was determined using a modified Penman approach (6, 13) and crop growth-by-season curves for the various crops grown in the irrigation district. This technique has been shown to be valid in southern Idaho. Surface runoff was determined by measuring the flow of natural surface drains throughout the period of sampling. The proportions of surface runoff and subsurface drainage water in natural surface drains conveying both were estimated by standard hydrograph separation techniques (9). Normal flow in these drains from December through March consisted of only subsurface drainage water from tunnels and tile-relief well networks. Canal company records and flow measurements showed that the subsurface drainage flows from these sources cycle yearly, with maximums in the fall and minimums in the spring. The flows in the surface drains and the contributing tunnels and tile-relief well networks were measured from December 1 through March 30. This procedure provided part of the yearly flow cycle for the subsurface water in these natural surface drains. The remaining portion of the yearly cycle was projected from the cycles for the contributing tunnels and tile-relief well networks. Thus, yearly flow cycles for the subsurface drainage water in these natural surface drains were computed. Measured flows in excess of the estimated subsurface drainage portion during the year were considered surface runoff. The change in soil water content, ΔS, was considered negligible because soils generally are low in water content at the beginning of each water year. The subsurface drainage or water that passed through the soil was computed by difference after measuring or estimating the other components in the equation. More than one-half of this subsurface drainage water was measured and sampled at the various tunnel and tile-relief well outlets.

RESULTS AND DISCUSSION

Estimated annual ET ranged from 1,072 mm (42.2 in.) for irrigated pasture to 584 mm (23 in.) for spring grain (Table 1). Values for the actual crop season are lower than those for the entire year because of evaporation from the soil during the period when no crop is growing. The weighted mean annual ET was 787 mm (31.0 in.).

The water balance (Table 2) showed that 50% of the total input water passed through the soil and became subsurface drainage. Evapotranspiration accounted for 36%, and the remaining 14% was surface runoff. Thus, 64% of the total water input became irrigation return flow into the Snake River.

The mean electrical conductivity (EC) of water di-

Table 1—Crops grown on the Twin Falls Canal Co. tract and the estimated evapotranspiration (ET) for each

Crop	Hectares	ET Entire year	ET Crop season	Acres	ET Entire year	ET Crop season
		—— mm ——			—— inches ——	
Alfalfa (Medicago sativa L.)	15,301	1,054	993	37,811	41.4	39.1
Dry beans (Phaseolus spp.)	14,299	630	498	35,333	24.8	19.6
Spring grain	9,835	584	480	24,302	23.0	18.9
Irrigated pasture	8,750	1,072	1,018	21,623	42.2	40.1
Sugarbeets (Beta vulgaris L.)	8,526	828	762	21,069	32.6	30.0
Corn (Zea mays L.)	6,380	706	597	15,765	27.8	23.5
Fall grain	3,278	612	498	8,100	24.1	19.6
Potatoes (Solanum tuberosum)	1,618	759	668	3,997	29.9	26.3
Peas (Pisum sativum)	862	617	516	2,130	24.3	20.3
Towns, canals, etc.*	8,094	1,072	1,018	20,000	42.2	40.1
Nonirrigated area	5,088	196	-	12,570	7.7	--
Total	82,030	-	-	202,700	--	--
Weighted mean	-	787	-	-	31.0	--

* Considered the same as for irrigated pasture.

Table 2—Water balance for the 82,030-ha (202,700-acre) Twin Falls Canal Co. tract for the water year, October 1, 1968 through September 30, 1969

	Metric $m^3 \times 10^4$	Metric mm	English acre-feet	English inches	%
Input					
Diverted from Snake River	159,134	1,941	1,290,000	76.4	89
Runoff from South Hills	3,948	48	32,000	1.9	2
Precipitation	16,049	195	130,000	7.7	9
City of Twin Falls	111	--	900	--	0
Total	179,242	2,184	1,453,000	86.0	100
Output					
Evapotranspiration	64,597	787	523,650	31.0	36
Surface runoff	25,151	307	203,880	12.1	14
Subsurface drainage	89,494	1,090	725,470	42.9	50
Total	179,242	2,184	1,453,000	86.0	100

verted at Milner Dam averaged 460 μmhos/cm, with little variation (Table 3). This value was used for calculating the total salt input (Table 4), since variation was slight. Surface runoff water had the same EC value as did the diverted water. Hence, the mean value of 460 μmhos/cm was also used for computing total salt outputs via surface runoff.

The total soluble salt concentration in subsurface drainage water was generally more than twice that in the irrigation water (Table 3). The concentration was nearly constant for each tunnel and tile-well network, but there was some variation among them. There was no particular pattern to the variation, and generally, differences were small. Thus, the mean EC value of 1,040 μmhos/cm was used for computing the total soluble salt output via subsurface drainage water (Table 4).

PO_4-P concentrations in water diverted from the Snake River ranged from 0.015 to 0.148 ppm. Concentrations were lowest during June and July during and immediately following peak river flow resulting from snowmelt. Because of the variation in PO_4-P concentration over the year, monthly mean PO_4-P concentrations were used with monthly water diversions to compute the total PO_4-P input (Table 4). Using the mean concentration of 0.066 ppm for the year gave a slightly higher input of 105 metric tons (116 English tons).

Subsurface drainage waters were so low in PO_4-P that it was necessary to concentrate samples to verify results by the sensitive method used (23) (Table 3). The mean concentrations for the various subsurface drainage effluents

Table 3—Mean concentrations of total salts, PO_4-P, and NO_3-N in irrigation and drainage waters of the Twin Falls Canal Co. irrigation tract

	Site no.	Total salts	PO_4-P	NO_3-N
		μmhos/cm	ppm	ppm
Milner Dam diversion	1	460	0.066	0.12
Surface runoff	2-5*	460	0.066	0.12
		Tunnels		
Clear	6	1,148	0.013	4.02
Fish Hatchery	7	867	0.013	2.24
Grossman	8	911	0.014	2.25
Nye	9	990	0.009	2.44
Tolbert	10	1,130	0.012	3.30
Walters	11	1,112	0.008	3.47
Mendini	12	1,106	0.009	3.97
Neyman	13	1,102	0.011	3.40
Galloway	14	982	0.014	3.58
Cox	15	973	0.015	3.44
Herman	16	1,076	0.017	3.00
Harvey	17	965	0.008	3.39
Peavy	18	984	0.007	3.02
Padget	19	1,000	0.008	3.01
Hankins	20	1,093	0.012	3.55
		Tile-Well Complexes		
Brown	21	1,121	0.009	3.01
Hutchinson	22	1,106	0.012	3.20
Kaes	23	1,044	0.023	3.40
Molander	24	1,088	0.009	3.79
Harvey	25	1,000	0.023	3.30
Mean for subsurface drainage water		1,040	0.012	3.24

* Surface 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.

Table 4—Total water-soluble salts, PO_4-P, and NO_3-N balances for the 82,030-ha (202,700-acre) Twin Falls Canal Co. irrigation for the water year, October 1, 1968 through September 30, 1969

	Metric tons*			English tons		
	Soluble salts	PO_4-P	NO_3-N	Soluble salts	PO_4-P	NO_3-N
Inputs						
In diverted Snake River water	467,584	84	190	515,414	93	210
In runoff from South Hills	5,128	--	--	5,563	--	--
Total	472,712	84	190	520,977	93	210
Outputs						
In surface runoff	73,900	14	29	81,459	16	32
In subsurface drainage	595,648	11	2,898	656,618	12	3,194
Total	669,584	25	2,927	738,077	28	3,226
Net input	--	59	--	--	65	--
Net output	196,871	--	2,737	217,100	--	3,016

* Total salt concentrations were obtained by multiplying the μmhos/cm × 0.64 to give ppm. The total yearly quantities of all constitutes measured were obtained by multiplying the concentration × total yearly flow on a weight basis.

did not differ widely. Hence, the mean value of 0.012 ppm was used for computing PO_4-P outputs. PO_4-P concentrations were generally lower than those reported by Johnston et al. (7) in subsurface drainage from California soils. The solubility of P compounds in calcareous soils at pH 8.2 is very low (3, 4, 10), and observed values are reasonable. Surface runoff water contained the same concentration of PO_4-P as did the irrigation water.

The NO_3-N concentration in water at Milner Dam was low, averaging only 0.12 ppm (Table 3). However, on two sampling dates during the winter when water was not being diverted, the concentration was about 1.50 ppm, indicating occasional increases in upstream inputs during low flows. The mean value of 0.12 ppm was used for computing NO_3-N inputs (Table 4).

Subsurface drainage water contained many times more NO_3-N than did the irrigation water, but concentrations were relatively low compared with Public Health Standards of 10 ppm as a maximum for drinking water. The mean value was 3.24 ppm, and variation within and among drainage effluents was small. Thus, the mean value was used for computing NO_3-N outputs. Surface runoff water contained the same concentration of NO_3-N as did the irrigation water.

Samples collected on several dates from all sampling sites were analyzed for NH_4-N and NO_2-N by microdiffusion techniques, but no detectable concentration of either was found.

The net output of 196,871 metric tons (217,100 English tons) of total soluble salts (Table 4) represents approximately 2.4 metric tons/ha (just over 1 English ton/acre). These salts arise largely from solubilization of soil minerals. Leaching occurs each year because 50% of the input water passes through the soil and becomes subsurface drainage. This high level of leaching assures against salt accumulations in the soil, but it also likely increases the salt output via subsurface return flows to the Snake River. Little or no precipitation of $CaCO_3$ or $CaSO_4$ occurs under these excessive leaching conditions. A salt balance is maintained in the sense that as much or more salt leaves the irrigation tract as enters it (24, 25), but such a balance probably could be maintained with less leaching. More efficient irrigation would probably decrease the total salt load in return flow and thus decrease the downstream salt load in the Snake River.

Irrigating the Twin Falls Canal Co. tract contributes to the total soluble salt load in the Snake River downstream. The contribution is not too serious because $579{,}792 \times 10^4$ m^3 (4.7×10^6 acre-feet) of water enters the river each year from the Thousand Springs, adjacent to and downstream from the tract. This water has an EC of about 250 to 300 μmhos/cm and, thus, dilutes the salt load in irrigation return flows. Furthermore, the subsurface drainage water from the tract contains lower total salt concentrations than does the irrigation water diverted in many locations from the Colorado and Rio Grande Rivers (1, 2).

Using water for irrigation decreased the PO_4-P load in the downstream Snake River. Approximately 30% as much PO_4-P leaves the tract in the drainage water as enters in the irrigation water (Table 4). Hence, 70% of the input in the irrigation water remains in the soil or is taken up by plants. Furthermore, there is no evidence that applied P fertilizers leached into the drainage water as PO_4-P. The estimated yearly application of P fertilizer is 2,460 metric tons (2,735 English tons) and only 11 metric tons (12 English tons) of PO_4-P left the tract in the subsurface drainage water. At some sampling dates the irrigation water contained measurable polyphosphate concentrations, whereas the subsurface drainage waters did not. Also, the organic matter load of the irrigation water was appreciable, and it contains some organic phosphates. In contrast, the subsurface drainage waters were essentially free of organic matter. All these factors add to the total P input into the Twin Falls Canal Co. tract but have little or no effect on the P output in the drainage water from the tract.

The net NO_3-N output of 2,737 metric tons (3,016

English tons) amounts to about 33 kg/ha (30 lbs/acre) per year. The origin of the NO_3-N is not definitely known, but possible sources are: (i) nitrification processes resulting from decomposition of plant residues including plowed alfalfa, (ii) applied N fertilizer, (iii) feedlots (18), (iv) farm-home sewer systems, (v) industrial wastes, (vi) leaching from semidesert soils, and (vii) precipitation. The relative importance of these NO_3-N sources is not known.

Results from this investigation should be applicable in principle to much of the western USA where calcareous soils are irrigated. The variation among irrigation districts will depend primarily upon the water balance, land management, and geology of the areas. A lower net output of total soluble salts and NO_3-N should be expected in districts where a smaller fraction of the applied water passes through the soil to become subsurface drainage. A higher net output of these components should be expected where a larger fraction of the input water becomes subsurface drainage. The PO_4-P balance depends upon the input. Where irrigation waters contain essentially no PO_4-P, the balance would be quite different on a percentage basis than where they contain considerable amounts. If the irrigation water contains PO_4-P, most of it will be removed by the irrigation process, and subsurface drainage water will contain an extremely low PO_4-P concentration.

Return flows from water diverted for irrigating calcareous soils in the West may contribute to the downstream total soluble salt and NO_3-N loads of the source stream. The amounts contributed will depend primarily upon the water balance and the amount of leaching. Sufficient leaching to maintain a salt balance is necessary for continued productivity of any irrigation tract. More than that amount of leaching may contribute more soluble salt and NO_3-N than necessary to the stream carrying away the drainage water—usually the source stream. The picture is different with PO_4-P. Irrigation decreases the downstream soluble PO_4-P load if the irrigation water contains more than about 0.01 to 0.02 ppm. The PO_4-P is precipitated as water passes through the soil. Of course if the irrigation water contains less than that concentration of PO_4-P, irrigation will have no effect on the downstream soluble PO_4-P load. Under these latter conditions, PO_4-P loads are unimportant.

LITERATURE CITED

1. Bower, Charles A., James R. Spencer, and Lowell O. Weeks. 1969. Salt and water balance, Coachella Valley, California. J. Irr. Drain. Div., Proc. Amer. Soc. Civ. Eng. 95 (IR1):55–64.
2. Bower, C. A., and L. V. Wilcox. 1969. Nitrate content of the upper Rio Grande as influenced by nitrogen fertilization of adjacent irrigated lands. Soil Sci. Soc. Amer. Proc. 33:971–973.
3. Cole, C. V., and S. R. Olsen. 1959. Phosphorus solubility in calcareous soils: I. Dicalcium phosphate activities in equilibrium solutions. Soil Sci. Soc. Amer. Proc. 23:116–118.
4. Cole, C. V., and S. R. Olsen. 1959. Phosphorus solubility in calcareous soils: II. Effects of exchangeable phosphorus and soil texture on phosphorus solubility. Soil Sci. Soc. Amer. Proc. 23:119–121.
5. Hamon, W. Russell. 1966. Evapotranspiration and water yield predictions. *In:* Evapotranspiration and its role in water resources management. Conf. Proc., Amer. Soc. Agr. Eng. p. 8–9.
6. Jensen, Marvin E., and David C. N. Robb. 1970. Scheduling irrigations using climate-crop-soil data. J. Irr. Drain. Div., Proc. Amer. Soc. Civ. Eng. 96 (IR1):25–28.
7. Johnston, William R., F. Ittahadieh, Richard M. Daum, and Arthur F. Pillsbury. 1965. Nitrogen and phosphorus in tile drainage effluent. Soil Sci. Soc. Amer. Proc. 29: 287–289.
8. Kuentzel, L. E. 1969. Bacteria, carbon dioxide and algal blooms. J. Water Pollut. Contr. Fed. 41:1737–1747.
9. Linsley, R. K., M. A. Kohler, and J. L. H. Paulhos. 1949. Applied hydrology. McGraw-Hill, New York.
10. Murrman, R. P., and Michael Peech. 1969. Effect of pH on labile and soluble phosphate in soils. Soil Sci. Soc. Amer. Proc. 33:205–210.
11. National Technical Advisory Commitee on Water Quality Criteria. 1968. Research Needs. US Dept. Int., Fed. Water Pollut. Contr. Admin. p. 69–70.
12. Olsen, S. R., F. S. Watanabe, and C. V. Cole. 1960. Soil properties affecting the solubility of calcium phosphates. Soil Sci. 90:44–50.
13. Penman, H. L. 1963. Vegetation and hydrology. Tech. Commun. no. 53, Commonwealth Bureau of Soils, Harpenden, England, 125 p.
14. President's Science Advisory Committee. 1965. Restoring the quality of our environment. Report of the environmental pollution panel. The White House.
15. Smith, George E. 1967. Fertilizer nutrients as contaminants in water supplies. p. 173–186. *In* N. C. Brady (ed.) Agriculture and the quality of our environment. Amer. Ass. Advance. Sci. Pub. 85.
16. Standard methods for the examination of water and wastewater. 12th Ed. 1965. Amer. Pub. Health Assoc., Inc. p. 236–238.
17. Stewart, B. A., F. G. Viets, Jr., G. L. Hutchinson, and W. D. Kemper. 1967. Nitrate and other water pollutants under fields and feedlots. Environ. Sci. Technol. 1:736–739.
18. Sylvester, Robert O., and Robert W. Seabloom. 1963. Quality and significance of irrigation return flow. J. Irr. Drain. Div., Proc. Amer. Soc. Civ. Eng. 89 (IR3):1–27.
19. Taylor, Alan W. 1967. Phosphorus and water pollution. J. Soil Water Conserv. 22:228–231.
20. US Salinity Laboratory Staff. 1954. Diagnosis and improvement of saline and alkali soils. USDA Agr. Handbook no. 60. L. A. Richards (ed.).
21. Utah State University Foundation. 1969. Characteristics and pollution problems of irrigation return flow. US Dept. Int., Fed. Water Pollut. Contr. Admin., 237 p.
22. Wadleigh, Cecil H. 1968. Wastes in relation to agriculture and forestry. USDA Misc. Pub. no. 1065. 112 p.
23. Watanabe, F. S., and S. R. Olsen. 1965. Test of an ascorbic acid method for determining phosphorus in water and $NaHCO_3$ extracts from soil. Soil Sci. Soc. Amer. Proc. 29:677–678.
24. Wilcox, L. V. 1963. Salt balance and leaching requirements in irrigated lands. USDA Tech. Bull. no. 1290.
25. Wilcox, Lloyd V. 1962. Salinity caused by irrigation. J. Amer. Water Works Ass. 54:217–222.