RESEARCH TECHNICAL COMPLETION REPORT
PROJECT A-028-IDA

WATER
for
IDAHO

Investigation of Factors Relative to Ground Water Recharge in Idaho

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Water Resources Research Institute
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CHAPTER I

INTRODUCTION

This project has concentrated on four of the myriad of factors relative to recharge of ground water in Idaho. The four factors are:

(1) An evaluation and application of methods for delineating large areas which can be safely utilized for the terrestrial disposal of wastewater. Inherent in almost any terrestrial disposal operation is the probability of ground-water recharge (Chapter II).

(2) Investigation of the effect of a terrestrial disposal operation on soil water and ground water in the vicinity of a sweet corn canning operation at Buhl, Idaho. The nature of the water reaching the zone of saturation beneath the disposal operation is of paramount importance because of the possibility of contamination of the ground-water body by recharge resulting from the disposal of the sweet corn process wastewater (Chapter III).

(3) An examination of changes in soil properties resulting from the application of wastewater, particularly sweet corn canning process effluent. These chemical changes can be expected to influence the life of a disposal site and to influence the quality of water which reaches the water table (Chapter IV).

(4) An investigation of a ground-water flow system in a mountain valley including the application of a mathematical model to the ground-water flow system in order to evaluate its role in the hydrologic budget of the valley. The contribution of the ground-water flow system is influenced by its recharge and discharge areas in addition to other factors (Chapter V).

CHAPTER II

DELINEATION OF AREAS FOR THE TERRESTRIAL DISPOSAL OF WASTEWATER

Problem

The population centers of southern Idaho near the Snake River are among the most rapidly growing communities of the State. Expansion is apparent where large irrigation projects are feasible and where resources for industrial and recreational development are available. Expansion is contributing a growing supply of wastewater to the already degraded streams of the Snake River Basin. At the same time, agricultural and industrial expansion is becoming increasingly dependent on a ground-water supply whose quality could be degraded by inadvertent recharge of polluted surface water.

The Idaho Falls-Blackfoot area near the upper reaches of the Snake River in Idaho (Figure II-1) is considered typical of several on the Snake River plain and solutions to waste-water and ground-water problems here should be applicable and beneficial to other communities throughout the Snake River Basin. In essence, the need in all of these communities is to find an economical method of disposing of industrial and domestic wastewater which does not result in the degradation of surface water or ground water.

Solution

Currently, reuse of river water occurs before natural renovation can take place; yet multiple use of river water must be insured because it is the basic economic resource of the area. Any satisfactory solution to local waste-water disposal problems must not merely pass the problem on to the public downstream and impose conditions which are detrimental to the municipal, agricultural, fishery, recreation or industrial needs of others. The solution, likewise, must not degrade the ground-water resources on which others depend. As an answer to the existing problem, terrestrial disposal of wastewater for irrigation and fertilization with its concomitant renovation and ground-water recharge is recommended herein. Under proper hydrogeologic conditions, irrigation or surface application of many wastewaters to farm, pasture or timber lands can provide an economical means of advanced treatment and renovation and at the same time contribute nutrients for increased crop production. The methods we have developed by which potential waste-water disposal sites can be rapidly and economically selected so that tertiary treatment can be avoided are outlined in this Chapter.

Background

The impoundment of waters in reservoirs has led to the accumulation and concentration of partially decomposed organic matter from inadequately treated municipal sewage discharges, from livestock wastes and from potato, sugar beet, wood pulp and other processing plant effluents. Algae and aquatic biota flourish on the added nutrients with the net result that the solar heated, stilled waters become oxygen deficient. Fish kills from oxygen deficiencies occurred in 1960, 1961, 1962, and 1966 in the Portneuf River near the southern margin of the Idaho Falls-Blackfoot area, in American Falls Reservoir to the west and in Milner and other reservoirs downstream on the Snake River. Decay of organic matter and its accompanying tastes and odors have made water-contact recreation undesirable in several stretches of the Snake River and have forced some cities, such as Twin Falls, to abandon this stream as a domestic water supply (U.S.D.I., 1968).

More specifically, the Federal Water Pollution Control Administration (now the Federal Water Quality Administration) as early as 1968 pinpointed the reaches of the Snake River below Idaho Falls and Blackfoot as pollution problem areas because of both domestic and industrial wastes (U.S.D.I., 1968). For 1967, Idaho

Falls and Blackfoot waste productions are listed as 1,300,000 and 192,000 population equivalents respectively. For the same year Idaho Falls and Blackfoot waste discharges amounted to 442,400 and 82,000 population equivalents. In the vicinity of Idaho Falls the Rogers Brothers Company, the Utah-Idaho Sugar Company, and the R. T. French Company discharged 110,000, 120,000, and 85,000 population equivalents of waste respectively. At Blackfoot the American Potato Corporation discharged 72,000 population equivalents of waste in 1967 (U.S.D.I., 1968). Some reductions have occurred subsequent to 1967, but the situation is far from satisfactory. In this same time interval annual municipal demands for ground water in Idaho Falls and Blackfoot alone have reached 19,570 and 495 acre feet respectively (Young and Harenberg, 1971).

This Chapter presents a methodology study to establish a systematic evaluation procedure through which municipal and industrial groups can delineate areas having satisfactory characteristics for the disposal of wastewater for irrigation and fertilization and coincident ground-water recharge.

Evaluation Procedure

A realistic program for the terrestrial disposal of wastewater must: (a) provide reliable protection for surface water, (b) guard against contamination of ground water, (c) permit renovation of degraded water by bacteria in an aerobic environment, (d) minimize decreases in infiltration capacity caused by dispersion of clays, and (e) require minimal design and supervision expenditures. The methodology for determining whether an area is suitable for waste-water reuse must take into account the requirements listed above and do so easily and quickly so that large areas can be evaluated on a routine basis. If this latter condition is not met, the process cannot be expected to be successful on a large scale.

The literature and our own investigations, much of which are summarized by Williams, Eier and Wallace (1969), indicate that the physical conditions necessary to satisfy the above requirements can best be supplied by: (1) gently sloping topography, (2) thick subsurface section of unconsolidated material, (3) adequate zone of aeration in the unconsolidated material, (4) soil or surface mantle with grain-size distribution in the silt-sand range and (5) subsurface hydrostratigraphic units with predictable ground-water characteristics and flow systems.

The gently sloping topography criterion promotes easy control of runoff to protect nearby surface water; it also alleviates many design and supervision problems. In combination the thick, unconsolidated section and the thick unsaturated section criteria provide maximum opportunity for filtration and ion exchange and for aerobic soil bacteria to renovate the wastewater; it also minimizes the chances of unrenovated wastewater moving directly downward to ground water through fractures or other highly permeable zones. The silt-sand size particles at ground-surface level can be expected to provide optimal filtration and infiltration without loss of capacity caused by dispersion of clay minerals. The delineation of subsurface hydrostratigraphic units criterion contributes insight into where coincident groundwater recharge will occur and where renovated wastewater will migrate and be reused again.

Area Evaluated

The Idaho Falls-Blackfoot area (Figure II-1) was one of the areas which Williams, Eier and Wallace (1969) showed to have potential for waste-water renovation through irrigation. In the study reported herein the area was evaluated in detail utilizing the criteria listed previously.

Selection of Terrestrial Wastewater Disposal Sites

Methodology

The procedure for selecting hydrogeologically suitable waste-water disposal sites necessitated the construction of a number of very detailed maps to permit analysis of the data; unfortunately, however, scale problems permit the inclusion of generalized versions only in this report (Figures II-2 through II-9).

First, topographic maps of the area were inspected and areas of low relief were chosen for field examination. The selected areas included the nearly horizontal flood plain and terrace surfaces along the Snake River and the gently dipping basalt plain to the west of the river (Figure II-2). Next, in order to delineate the thickness of unconsolidated sediments in these areas of low relief and then to determine the thickness above the water table in which aerobic conditions persist, contour maps were prepared of both the depth to the water table (Figure II-3) and of the bottom of the unconsolidated sediments (Figure II-4). These maps were then combined with topographic maps and cross contoured to construct a map depicting the thickness of the unsaturated, unconsolidated interval (Figure II-5). Contour intervals which were used on this thickness map separated unsaturated and unconsolidated material into thicknesses that have significantly different waste-water renovation capacities. The selected intervals were less than 10 feet (low disposal potential, although as little as five feet can be tolerated if careful management procedures are followed), 10-to-50 feet (moderate disposal potential), 50-to-100 feet (good disposal potential), and greater than 100 feet (high disposal potential).

Most of the unconsolidated-sediment data used in preparing the maps were obtained from drillers' logs and other types of well logs. The drillers' logs proved to be very useful because only the depth of the first change from unconsolidated sediments to bedrock was critical. Water-level data used to construct the water-table map were obtained from well soundings. Only shallow wells were measured in order to minimize errors caused by changes in fluid potential with depth or by the fluid potential distribution in confined aquifers.

Data on soil characteristics which were required to delineate areas with desirable filtration properties were then gathered and plotted. Most were obtained from studies by Chugg and others (1968a and 1968b), by Poulson and others (1943), and by Morgan and Poulson (1950). Soils classified as silty loams, sandy loams, and silty clay loams were selected as most promising for waste-water disposal because of their appropriate grain-size distribution with respect to infiltration, dispersion and renovation characteristics (Figure II-6).

To predict the effect of artificial recharge on the existing shallow groundwater flow system and to understand which subsurface units would likely receive and conduct wastewater, two maps, a water-table contour with generalized flow net (Figure II-7) and a geology map (Figure II-8) were constructed from field and aerial photograph observations. Comparisons of these two maps helped identify the subsurface rocks through which ground water currently is flowing and determine what might be the subsurface flow characteristics and renovating capacities of the hydrostratigraphic units which these form. More detailed discussions of the individual site selection criteria and how they were evaluated for the Idaho Falls-Blackfoot area follow.

Topographic Criterion

Variations in the topography of the Idaho Falls-Blackfoot area are strongly influenced by the rock types of the area (Figures II-2 and II-7). Tertiary and older Pleistocene silicic volcanic rocks and associated sediments form the steep-to-rolling foothills of the Blackfoot Mountains south and east of the Snake River. These foothills are generally too steep for waste-water disposal on a large scale. Younger Quaternary Snake River basalt flows which accumulated north and west of the Snake River form a low irregular surface; this low-relief surface does satisfy the topographic criterion. Between the Blackfoot Mountains and the outcrops of the Snake River basalt are the Quaternary fluvial sediments which make up the nearly horizontal flood plain and terraces of the Snake River. These low-relief surfaces also conform to the topographic criterion.

Locally the irregularities of the slopes and surfaces of both the foothills and the basalt plain have been softened by a loess mantle. Longitudinal sand dunes also have given an irregular surface to some of the terrace surfaces. Neither of these surficial deposits, however, had modified the characteristic expression produced by the underlying rock types enough to alter the general evaluation of potential waste-water disposal areas based on the topographic criterion.

Topographically, then, both the low basalt and the nearly horizontal flood plain and terrace surfaces along the Snake River meet the topographic criterion for waste-water disposal. Many of the other major cities of south Idaho are also situated on this surface of low relief, called the Snake River Plain, and, therefore, they appear cursorily to be favorably located with respect to satisfying the topographic criterion for waste-water disposal.

Unconsolidated Section Criterion

Those areas of low relief on the Snake River Plain in the Idaho Falls-Blackfoot vicinity which have an adequate subsurface thickness of unconsolidated material for consideration as waste-water disposal sites are typically restricted to the terraces and flood plain of the Snake River (Figure II-4). The partially exposed basalt flows west of the river may have a thin loess mantle, but this unconsolidated material seldom was found to be sufficiently widespread or thick to merit any serious consideration in site selection.

The principal materials making up the unconsolidated section beneath the nearly horizontal flood plain and terrace surfaces are fluvial silts, sands and gravels capped by soil. The fluvial material forms a single hydrostratigraphic unit which has desirable renovating and storage characteristics for waste-water handling.

To generalize, the unconsolidated fluvial material thickens southeastward between the soil cover and the underlying basalt flows. Northwest of the Snake River thicknesses in excess of 50 feet are seldom encountered; southeast of the river as much as 600 feet of unconsolidated material was mapped. This wedge shaped distribution of alluvial material makes the Pinedale Terrace south of Idaho Falls (one major waste-water source) and the Gibson Terrace south of Blackfoot (a second major waste-water source) potential waste-water disposal sites based on the unconsolidated section criterion. The thick unconsolidated section is continuous between the two cities and is located in proximity of additional waste-water producing processing plants and smaller communities.

The overall thinness and pinch-out of this material west of the Snake River is the major restricting factor limiting the number of potential waste-water disposal sites on this side of the river. The thinner unconsolidated sections forming the low terraces west of Blackfoot and the Snake River are capable of moderate renovation because some localities do have minimal thicknesses of fluvial material above basalt bedrock. If disposal were attempted here, care would have to be taken to insure that wastewater did not have almost direct access through the thin unconsolidated section to permeable basalt below and subsequently to the groundwater table and springs located to the south.

Unsaturated Section Criterion

The degree to which the previously outlined thicker sections of unconsolidated fluvial sediments of the Snake River flood plain and terraces can be used for terrestrial waste-water disposal and renovation is further dependent on how well the unconsolidated material meets the unsaturated section criterion. Where a thicker section is present, as east of the river, the depth to the water table will determine the utility of that section for renovating wastewater in an aerobic environment.

In general, well soundings and water-table measurements show that the unsaturated zone in the unconsolidated sediments is thinner on the flood plain near the river or standing bodies of water, such as American Falls and Blackfoot Reservoirs (Figure II-5); the zone of aeration is thicker beneath the river terraces, the surfaces of which are now well above river level.

Specifically, the most promising areas for waste-water disposal within those areas which also satisfy the criteria of gentle topography and thick unconsolidated section are the terrace surfaces east and south of Idaho Falls and near the foothills south of Blackfoot. The unsaturated section above the local water table in these areas commonly exceeds 50 feet, a thickness considered adequate for normal waste-water disposal through irrigation. At some localities this zone of aeration approaches 100 feet, a thickness which can handle intense disposal if necessary.

The water table west of the river also is more than 100 feet below surface level in some locations (Figure II-3). Although this would indicate that the unconsolidated fluvial terrace deposits west of the river commonly have their entire thickness above the water table, it should be remembered that the terrace deposits are thin and the aerated zone would persist 50 or more feet down into the underlying basalt. This basalt has poor renovating characteristics and as observed in the preceeding section, once wastewater gains access to this material, even in the unsaturated zone, the chances of ground-water and surface-water contamination increase greatly.

Grain Size Criterion

The soil types which offer the most desirable characteristics with respect to infiltration rate and decreases in infiltration rate due to dispersion are generally those which have high silt and sand content. These are typically classified as silty, sandy or gravelly loams in the area of this study. These preferable soil types are commonly distributed on the tops of the thick unsaturated, unconsolidated terrace sections of the Snake River plain, therefore, the areas which have met the previously discussed topographic and unconsolidated and unsaturated section criteria also generally satisfy the soil criterion (Figure II-6).

The Idaho Falls area is almost surrounded by desirable soil types; the Blackfoot area has more desirable soil types south of the city and west of the Snake River. The sand dunes south of Idaho Falls also have the proper infiltration characteristics, unfortunately, growing conditions are far from ideal on the dunes, and much of the irrigation and fertilization aspect of waste-water disposal would be lost if terrestrial disposal was practiced here.

The higher sand content of the soils and the presence of dunes on the terrace surface east of the river represent the net effect of a dominant easterly wind direction and the availability of fluvial sand. This also explains the rather noticeable lack of soils with a desirable composition for infiltration on the low terraces and basalt flows west of the Snake River. The lighter, loessial materials which mantle parts of these surfaces apparently were derived at some distance from the study area on the Snake River plain; it is influences such as this which may give an entire area poor capability for the infiltration of waste-water.

A further subdivision of potential wastewater disposal sites has been made based on specific soil types (Figure II-9); this selection refinement is one of the final procedures prior to a field testing program.

Those potential disposal sites given a first-class rating are on soils which have low clay content plus the requisite silt and sand composition. Second-class sites are on soils which have a greater clay content but still contain adequate silt and sand for good permeability. Both classes of sites, nevertheless, are considered to have satisfactory infiltration characteristics for waste-water disposal and would merit consideration for this purpose. First-class sites can be expected to handle a higher sustained disposal rate and should be evaluated or selected preferentially if near a source of effluent.

Ground-Water Flow System Criterion

The shallow ground-water flow system in the study area is recharged by precipitation in the foothills, by influent streams flowing across the area and by irrigation on the cultivated land. The net effect of these sources is a shallow ground-water system which moves westerly from upland source areas, turns southwesterly beneath the Snake River plain and discharges, in part, near the southern limit of the study area either as seepage into American Falls Reservoir, as seeps forming the swamps on the Snake River flood plain or as springs along the truncated edges of the fluvial terraces (Figure II-8).

From a waste-water disposal point of view, the potential disposal sites in the Idaho Falls-Blackfoot area which satisfy the basic topographic, subsurface and infiltration criteria are in areas where the shallow ground-water system could utilize additional recharge from waste-water disposal through irrigation without adverse effect. Caution, however, might need to be exercised south of Blackfoot where springs appear near river level.

Currently, the more northeastern part of the Idaho Falls-Blackfoot area is strongly associated with the recharge portion of the recharge-discharge cycle of ground-water movement. Within the area of study, therefore, the farther a potential waste-water disposal site lies upstream relative to the Snake River, the better the potential site is located for safe and beneficial recharge to the ground-water flow system. In addition, ground-water quality studies (Dyer and Young, 1971) suggest that upstream disposal would be preferred because of a higher concentration of ions already present in the ground-water near the downstream discharge areas.

Disposition of wastewater through irrigation appears very feasible on the Pinedale Terrace near Idaho Falls. The Snake River, at least as far southwest as Blackfoot is losing water to the ground-water flow system and any wastewater disposed on the Pinedale surface which results in ground-water recharge north of the Blackfoot area will receive a final renovation during the long southwestward subsurface migration toward a discharge area. Locally, on the Pinedale Terrace, disposal should not be practiced near the margin of Blackfoot Reservoir because there the water table is near ground level (see Unconsolidated Criterion section).

Disposal areas south and east of Blackfoot can still be found which will not damage or significantly alter the shallow ground-water flow system; it is of particular importance to avoid the disposal of wastewater in the vicinity of the abrupt edge of Gibson Terrace near the Snake River flood plain. Seeps and springs do occur here and wastewater, if it were used in irrigation along the edge of the terrace, could migrate downward through the zone of aeration and reappear within a short distance. This wastewater normally probably would be renovated in the aerated zone, however, for maximum safety, disposal through irrigation should be limited to the western portion of the Gibson Terrace. Wastewater disposed in this vicinity would have to migrate a considerable distance before reappearing at the surface.

The same type of ground-water consideration should be applied in selecting disposal sites on low terraces on the west side of the Snake River in the limited number of areas which meet the other selection criteria. As a general rule, the farther that one selects an irrigation disposal site away from the American Falls Reservoir discharge area, the more desirable the site will be relative to ground-water quality considerations.

Recommendations for Final Selection of Terrestrial Waste-Water Disposal Sites

Before an irrigation project with wastewater is undertaken, some additional examination and on-site testing should be conducted. The major variables which should be examined and characterized before any large expenditures are made include:

1. The reaction of the specific effluent with the soil. Effluents have different constituents, and the chemical reactions and ion exchanges which will occur between the constituents and the site soil cover must be determined. Reactions and exchanges which are adverse to the crops, the soil, and to infiltration capabilities must be recognized early so that a new site can be considered or corrective treatment can be incorporated in the disposal procedure before damage occurs to the hydrostratigraphic unit.
2. The method of irrigation. Each method of irrigation has its advantages and disadvantages relative to the disposal of wastewater. It is of prime importance to ensure (a) that the effluent is well distributed over the surface of the infiltration field, (b) that the effluent does not accumulate into long-standing puddles or ponds, and (c) that a monitoring

system is incorporated into the design so that unforeseen conditions do not permit the effluent to migrate directly to naturally flowing streams or main irrigation ditches.

3. The rate of infiltration. The rate at which the silty, sandy soils can absorb wastewater should be determined through testing. This parameter will partially determine size of disposal area necessary to handle a specific amount of effluent or the loading which a single site can handle.

4. The local variations of the ground-water flow system. The water table beneath the terrace surfaces commonly fluctuates with the local irrigation season; it is lowest in the spring and highest in the fall. Any potential waste-water disposal site should be monitored through an irrigation season to affirm that nearby irrigation projects do not modify the ground-water flow system. Monitoring would also record what excessive variations occur and if the zone of aeration is temporarily reduced below that needed for adequate renovation.

5. The local variations in ground-water composition. Just as the local water table may reflect the influence of irrigation projects, so may the concentration of contaminants in the ground water. The source of irrigation water, whether river or well, influences the concentration of ions in ground water, and the concentration of these ions should be monitored through an irrigation season to identify the variations and ensure that waste-water disposal will not overload the renovation system.

6. The possibility of perched water tables. Careless management and an increase in infiltration rate may create a perched water table if stratified, moderately impermeable clay layers or cemented zones exist in the

Unconsolidated material. Well logs, geophysical surveys or borehole data will provide information on possible local barriers to downward waste-water movement. The subsurface section should be analyzed geologically with this possibility in mind to ensure that a waste-water site will not saturate the aerated zone. Geologic conditions also should not be such that they would permit springs and seeps to develop from perched water tables and emit unrenovated water to surface drainageways.

7. The nutrient value of the effluent. The components of the effluent which will affect or be utilized by vegetation need to be identified. Specific crops often respond better to specific nutrients, and a compatible crop-nutrient relationship should be established for economic use of the fertilization potential of domestic and livestock effluent. A few trace elements can be concentrated by some plants to levels harmful to animals; and if this possibility exists because of the nature of an industrial effluent, other disposal procedures should be considered. Spray irrigation of forested land is one possibility.

Summary

The disposal of municipal, industrial and livestock wastewaters into the Snake River and its tributaries is the source of a serious surface-water pollution problem in the southern part of Idaho. In some cases wastewater is also a threat to the ground-water resource. Renovation through irrigation with coincidental crop fertilization and ground-water recharge is proposed herein for hydrogeologically suitable portions of the Snake River Plain, in lieu of expensive tertiary, and in some cases secondary, treatment. The region near Idaho Falls-Blackfoot has been used as a case study area to establish the methodology for selecting suitable terrestrial disposal sites. The procedures utilized are sufficiently simple that they are readily adaptable to other larger areas.

Safeguarding surface-water and ground-water resources, providing for maximum probability of proper renovation of wastewater and minimizing design and supervision requirements are conditions which must be satisfied by any terrestrial waste-water disposal project. The criteria for selecting sites which meet these conditions for proper disposal and renovation include gentle topography, a thick subsurface section of unconsolidated, unsaturated porous medium, a surficial mantle of high sand-silt content and a well understood shallow ground-water flow system. Evaluation and mapping with respect to these criteria in the area between Idaho Falls and Blackfoot, Idaho, has facilitated the delineation of sections of land wherein successful terrestrial disposal of wastewater can be expected. The delineation of such areas permits municipalities to identify sites for terrestrial disposal of domestic wastewater, and it provides industry with the opportunity to select locations for future operations from which terrestrial disposal of wastewater is anticipated; such planning is essential to the elimination of nutrient enrichment of surface-water bodies in the future.

CHAPTER III

IRRIGATION WITH WASTEWATER FROM CORN CANNING OPERATIONS AT BUHL, IDAHO

Introduction

The effectiveness of a wastewater disposal program employed by the Green Giant Company of Buhl, Idaho, has been investigated. The aims of the study which was conducted with the cooperation of the company were:

1. Evaluation of hydrogeologic parameters at the disposal site
2. Chemical analysis of the wastewater
3. Determination of the degree of renovation achieved via terrestrial application of wastewater
4. Evaluation of recharge of ground water by percolating wastewater.

Soil Properties

For objective number one, a portable soil auger was used to drill numerous test holes at various points in fields used as disposal sites. These holes were drilled to the bedrock surface, and soil samples were extracted at three foot intervals, starting at the surface. Numerous analyses were conducted on these samples and they are presented in Table III-1. Field notes (summarized in Table III-2) were utilized for the construction of a topographic map (not shown) of the soil surface and of the bedrock surface. Additional information for depth of soil cover above bedrock was obtained by subsequent test boring by augers. The thickness of the unconsolidated zone was consistently nine feet or less, and in only one hole was a saturated zone recorded.

Figure III-1 is a map of the irrigated fields showing drill sites, sample points and instrument locations.

TABLE III-1

Size, Class and Diameter of Particles (mm.) (percent), pH, CEC

Site	#1				#2		#3			#4		#5		#6				#7			
Depth	0'	3'	6'	8'	0'	3'	0'	3'	6'	3'	4½'	0'	3'	0'	3'	6'	9'	0'	3'	6'	9'
Sands %																					
VCS	.07	.63	2.70	9.68	.22	.74	.10	.52	8.40	.03	1.72	.99	.12	.04	1.05	8.29	2.68	.13	.31	5.57	4.90
CS	.12	.56	2.28	7.48	.23	1.06	.13	.62	9.71	.13	1.40	.79	.22	.12	.55	7.24	3.51	.18	.17	5.06	5.47
MS	.16	.45	2.49	4.92	.16	.68	.14	.46	8.63	.10	.83	.54	.18	.07	.46	5.56	3.51	.17	.17	3.60	4.52
FS	.83	1.55	7.17	11.30	.92	1.97	.91	1.93	16.08	.66	2.60	2.04	.83	.60	1.70	7.70	7.75	.98	.95	8.25	10.67
VFS	11.65	13.84	23.70	22.88	13.48	13.27	11.80	17.08	18.38	10.76	16.71	14.65	12.77	11.71	17.02	14.11	12.61	12.73	12.88	18.94	21.16
Total*	12.84	17.04	38.75	56.28	15.03	17.73	13.08	20.61	61.20	11.68	23.26	19.02	14.13	12.54	20.79	41.90	30.07	14.19	14.49	41.43	46.72
Silts %																					
FS	2.94	2.60	4.13	1.93	3.00	3.65	3.13	3.15	2.00	3.03	3.12	3.01	3.33	3.00	3.78	2.52	6.09	2.67	2.53	2.50	3.09
MS	23.06	25.92	17.40	12.44	20.50	22.47	22.25	22.98	11.19	23.88	22.00	18.95	23.82	23.56	22.60	17.06	21.16	17.70	25.00	16.14	13.89
CS	38.90	41.95	26.55	20.24	41.77	32.62	41.70	39.30	15.64	43.95	32.62	43.86	42.22	39.54	39.16	24.54	22.20	47.25	40.43	23.73	22.33
Total	64.89	70.48	48.09	34.62	65.28	58.74	67.07	65.44	28.84	70.86	57.74	65.82	69.36	66.11	65.54	44.11	49.45	67.62	67.96	42.37	39.31
Clay %	22.28	12.48	13.16	9.10	19.69	23.53	19.84	13.95	9.96	17.46	19.00	15.16	16.50	21.34	13.68	13.99	20.48	18.18	17.55	16.20	13.97
Gravel-Stone %	T	T	10.79	18.50	T	11.74	T	T	28.08	0	6.86	T	0	T	2.63	34.18	8.79	T	T	12.57	8.48
Texture Class	SL	SL	L	GFSL	SL	SL	SL	SL	GFSL	SL	SL	SL	SL	SL	SL	GL	L	SL	SL	L	L
pH	7.75	8.12	8.35	8.10	7.80	8.10	7.60	8.18	8.31	7.95	8.10	8.20	8.12	7.65	7.95	8.00	8.12	7.95	7.95	8.30	8.15
CEC	23.78	18.47	15.75	15.55	21.84	21.01	23.78	18.27	13.79	17.55	20.71	19.49	17.24	23.98	17.75	12.56	33.16	21.12	15.92	17.84	21.94

*Totals may not be exact sum of constituents because of small analytical error.

TABLE III-2

Drill Data

Late Cornfield (not shown in Figure III-1, 32 acres)

1. Clay to 4', approximately 1-1/2' gravel (larger than usual pea-size), then a light-colored fine sand layer, to bottom at 9'1". Dry.

2. Four feet of clay; then gravel 1-1/2' thick. Bedrock 8'6" down.

3. Hit gravel at 3', 40-1/2" deep. Dry.

4. Hit gravel at 3', hole 57" deep.

5. Hit very wet clay at 3', and drilling was very easy after this layer was hit. No gravel encountered, hole 51" deep and dry.

6. At 3' is clay, at 5' is hardpan, dry. At 8-1/2' is wet, easy drilling. At 11-12' gets very hard to drill through hard-packed clay which stalls the drill very easily. The clay is moist but relatively dry for this depth. Two holes, deep hole is 16'7", with 7'9" of water (8'10" to water table). Shallow hole is 14'11" deep with 6'3-1/2" of water (8'7-1/2" to water table).

7. Gravel at 2', down to 3-1/2-4'. Hold 4' deep. Dry.

8. Hole still only 4', but the clay was quite moist at time of drilling. Hole is dry now.

9. Evidently no obvious gravel layer, clay to bottom of hole? First hole 85", with 29" of water (56" to water table). NOTE: Examination of site three days later showed no standing water; so only a temporary perched zone.

Late Cornfield (9A in Figure III-1)

1. 62" deep, clayey soil overlying bedrock, no water, no gravel, and hole is 5' from large irrigation ditch carrying water all of the time.

2. Clayey soil down to 4-1/2', gravel from 4-1/2-6' with hard drilling in this stretch of profile. Beneath 6' the drilling was easier, hole depths are 107" and 90", both dry.

3. At 4-1/2' hit pea-gravel, at 6' drilling was much easier, the clay quite wet, mixed with gravel. Holes are 113-1/2" and 89". Dry.

4. Shallow, only one hole, 49-1/2" deep, no gravel.

Barley Field (8 acres)

1. Hit very wet clay at bottom of hole, at time of drilling I was sure that water table had been reached, but a check six days later shows dry hole. Drilled to 91", but no piezometers established yet. The holes were hard drilling at 4-5-1/2', with hard clay or clay and gravel mix. After this difficulty the holes went fast as the very wet clay was encountered.

TABLE III-2, Continued

Barley Field (8 acres), Continued

2. Shallow, down to around 3'.
3. Hit gravel 4-1/2', hole approximately 6' deep.
4. Hole 5', no gravel.

Grain Size

Mechanical analysis of the soil particle-size distribution, analysis of cation exchange capacity and soil pH, and X-ray diffraction analysis of clay minerals present in the samples were conducted at laboratories on the University of Idaho campus. Mechanical analyses (see Table III-1) show that at the soil surface, grain-size distribution averages 14.45% sands (2-0.05 mm), 66.13% silts (0.05-0.002 mm), and 19.41% clay-sized particles (<0.002 mm). This soil is classified as a silt loam.

At a depth of 3 feet, the soil column averages 16.64% sands, 66.91% silts, and 16.98% clays. At 6 feet, the average is 45.82% sands, 40.85% silts, and 13.58% clays. At the few sites where the soil column was 9 feet deep the averages were 44.36% sands, 41.13% silts, and 14.52% clays. Thus the soil column varies from a silt loam at the surface, silt loam at three feet, to a gravelly fine sandy loam at six feet, and to a loam at nine feet.

Soil pH

pH analysis of the soil samples (Table III-1) illustrated that the soil was slightly basic. At the surface, pH averaged 7.71, at the three-foot depth it averaged 8.05, at six feet it was 8.24, and pH at nine feet was 8.12. Associated cation exchange capacity (Table III-1) varied from an average of 22.33 meq./100 gm at the surface, to 18.03 meq./100 gm at three feet, 12.49 meq./100 gm at six feet, and 23.55 meq./100 gm at nine feet.

Clay Minerals

For X-ray diffraction analysis, sample material was air-dried and then sifted through a #200 sieve (.074 mm). Included in the sample for analysis was both silt and clay-sized material. Most surface samples indicated the presence of an amorphous to poorly crystalline material-possibly allophane or glass shards in ash. In general the samples are poor in clay minerals and consist mainly of quartz, carbonates, and feldspar. Table III-3 is a breakdown of the mineral types as detected by X-ray diffraction analysis.

TABLE III-3

Minerals Detected by X-ray Diffraction Analysis

Sample	Montmor-illinoids	Illite, Mica	Kaol-inite	Vermi-culite Chlorite	Quartz	Calcite	Feldspar
1-0'	Trace	Trace			X		X
3'	Trace				X	X	X
6'					X	X	X
8'					X	X	X
2-0'		Trace			X		X
3'					X	X	X
3-0'		Trace			X		X
3'					X	X	X
6'					X	X	X
4-3'	Trace				X	X	
4½'	Trace	Trace			X	X	X
5-0'	Trace	Trace			X	X	X
3'	Trace	Trace			X	X	X
6-0'	Trace	Trace			X		X
3'	Trace	Trace			X	X	X
6'					X	X	
9'	Trace				X	X	
7-0'	Trace	Trace	Trace		X		
3'	Trace	Trace			X	X	X
6'					X	X	X
9'					X	X	X

X indicates presence.

Renovation Potential

With the exception of soil thickness, the overall characteristics are well suited for the purposes of renovating high BOD wastewater. The generally low concentration of clay minerals, which ordinarily would result in relatively low cation exchange capacity for the soil, is compensated by relatively high concentrations of organic material incorporated within the soil. The presence of organic matter has thus given the soil a favorable exchange capacity, and at the same time has added to the tilth of the soil. The one major limitation for the two representative fields whose profiles are depicted in Figure III-1, is the general lack of adequate depth of unconsolidated material (soil cover) over the basalt bedrock. As will be shown later, this limitation along with the topography of the field, necessitates application rates less than optimal for plant growth.

Wastewater Characteristics

The second objective of the study, the chemical analysis of the wastewaters which Green Giant presently applies to its fields, encompasses data from two different years. Table III-4 is a summary of chemical analysis for corn starch wastewater derived from factory operations, ensilage drainage from solid corn wastes screened from the wastewater, and a summary of chemical quality characteristic of water from the Snake River irrigation diversion ditch. There is considerable variability in the data for the wastewater in 1969 and 1971. There is no question but that the wastewater is poor in quality. The high E.C., low pH, and high concentration of salts are all potentially detrimental if careful management techniques are not practiced.

An evaluation of the more important characteristics of the wastewater from the Green Giant operation can be accomplished by computing the sodium-adsorption ratio (SAR) of the effluent. The SAR and E.C. can then be used to determine the Salinity hazard and associated classification for this water as determined from the Department of Agriculture Handbook No. 60, page 80, for Table III-5.

TABLE III-4

Water Quality Data

Summary of Chemical Data for Wastewater, 1969

1969	pH	EC	DO	BOD*	Coli**	PO_4	N	Na	K	Mg	Ca	Cl^-
8- 8	4.0	33100	5.8					15120	540.0	180.0	320.0	
8-13	4.7	863	6.9					100	33.8	35.5	35.3	
8-28	3.6	835	7.3			2.78	2.9	102	72.5	26.3	14.5	99.0
9- 5	4.3	808	6.9			4.98	4.0	83	70.0	22.8	12.5	124.5
9-22	4.1	732	7.2			7.04	35.5	79	72.5	22.0	10.5	

Summary of Chemical Data for Wastewater, 1971

1971	pH	EC	Coli**	NO_3	Na	K	Mg	Ca	Cl^-
8- 9	7.4	4400		350.0	720	65	55	50	1126.4
8-10	6.9	3000		350.0	415	70	42	34	646.1
8-17	6.3	1275		1.2					127.1
8-23	5.8	1150			105	105	35	22	95.6
8-24	5.8	1140		1.2	115	87	42	18	101.2
9-11	4.1	800							

Summary of Chemical Data for Ditch Water from Snake River Diversion

1971	pH	EC	NO_3	Na	K	Mg	Ca	Cl^-
8-25	8.3	380	0.0	15.4	3.5	13.1	23.0	17.4
9-18	8.3	360						

*In all cases, there was insufficient dilution of sample to permit a reading of oxygen at the end of five-day incubation. The BOD of wastewater exceeds 17,000 ppm, and the upper limits of probable BOD can only be guessed at around 50,000 ppm.

**Nearly all samples of wastewater showed the presence of fecal coliform. MPN coliform counts at all times exceeded 240×10^6.

Summary of Ensilage Drainage

1969	pH	EC	DO	BOD*	Coli**	PO_4	N	Na	K	Mg	Ca	Cl^-
8- 8	5.1	1030	6.4					217.5	62.5	39.5	36.6	
8-13	3.2	8950	6.2					112	2240	900	670	990
8-19	4.7	1863	5.8			1500	194.8	3500	1600	300	620	4250
8-28	4.5	4625	7.2			45		14400	540	290	520	
9- 5	3.9	9437	7.3			60		310	2300	350	270	810
9-22	4.0	8420	7.3			60	296.8	67.2	2130	330	260	

*BOD exceedingly high, but never measured because of insufficient dilution. The maximum dilution used yielded a BOD in excess of 116,000 ppm.

**Coliform counts varied from MPN of 38,000 to 120,000. Counts were lower than the counts experienced with wastewater. Tests for presence of fecal coliform were not made because of inadequate laboratory facilities in 1969, but their presence is highly unlikely.

TABLE III-5

Computation of SAR for Wastewater, EC

Date	Na	Mg	Ca	SAR	EC	Classification
Aug. 8, 1969	15120	180	320	196	33100	Off the table
13	100	36	35	3.5	863	C3-S1
28	102	26	15	4.8	835	C3-S1
Sep. 5, 1969	83	23	13	4.3	808	C3-S1
22	79	22	11	4.2	732	C2-S1
Aug. 9, 1971	720	55	50	20.9	4400	C4-S4
10	415	42	34	14.2	3000	C4-S4
23	105	35	22	4.2	1150	C3-S1
24	115	42	18	4.5	1140	C3-S1

In general, the wastewater represents a sodium (alkali) hazard only for the early period of canning operations. But the salinity hazard remains high throughout the canning season. There is a plus-factor, though, that must be considered. This is the equivalent amount of commercial fertilizer present in the wastewater. One would expect that an effluent so highly loaded with organic constituents would prove of special value to crops as a fertilizing agent. Accordingly, equivalent values for nitrogen, potash, and phosphate in pounds per acre were computed for those dates when data permitted this computation.

Table III-6 is a summary of the fertilizer equivalent in the wastewater.

TABLE III-6

Fertilizer Components Present and Relative Amounts

Date	Lbs. P_2O_5/Acre-ft.	Lbs. N/Acre-ft.	Lbs. K_2O/Acre-ft.
Aug. 28, 1969	11.26	7.72	473.77
Sept. 5, 1969	20.18	10.84	457.43
Sept. 22, 1969	28.53	96.27	473.77

These figures represent highly significant amounts of fertilizer available for plant growth. The significance of both the salinity and alkali hazard, and the value of fertilizer components, will be evaluated subsequently.

Soil Water Sampling

Objective number three was the determination of the degree of renovation achieved via terrestrial application of wastewater. A number of soil water samples were obtained for analysis by means of tensiometer tubes. The tubes, consisting of 2-inch diameter plastic pipes 48 inches in length with a porous ceramic cup fixed over the bottom opening of the tube, were installed in vertical holes augered into the soil. The bottom of each hole is shaped into the dimensions of the ceramic cup to ensure a close fit and seal between the cup and the soil. After the tube is inserted into the hole and the cup is turned into the shaped bottom of the hole, the soil is tamped tightly around the tube to prevent the access of surface water to the tube. It is important that the wastewater not be allowed to flow around the tubes because this might very well contaminate the soil moisture sample.

The soil moisture sample was obtained by establishing a vacuum in the tube. A rubber stopper with a single hole drilled through its center and a short length of glass tubing fixed in the hole was placed over the top end of the tube. Air was pumped from the tube through the center opening in the stopper. A vacuum of about 1/3 atmosphere could be established with the simple hand pump used in the field. The vacuum served to draw soil moisture from adjacent soil into the tube through the porous ceramic cup.

In 1969 tubes were installed in pairs in the 9-acre field labeled as field 9-A in Figure III-1. One tube was installed at 24 inches. The second was installed at 48 inches. In addition, one shallow and one deep tensiometer were installed on the perimeter of the ensilage disposal site (Figure III-1).

For 1970 the researchers shifted their attention to the larger 18-acre field labeled 17-A in Figure III-1. For this sampling, tubes were installed at only one depth, that of 48 inches. The researchers were interested primarily in the determination of the quality of water percolating toward the water table. A separate research activity was subsequently devoted to the determination of interaction between soil and percolating wastewater at depths less than 48 inches within the soil column. That information is presented in Chapter IV of this report.

During 1971 the researchers installed instruments in fields 9-A and 17-A, and in a research plot, at the depth of 48 inches. For all three years the field position of instrument sites is indicated in Figure III-1. Data on the chemical nature of water samples are presented in Table III-7.

Renovation of Wastewater

In order to discuss the degree of renovation, we have compared the values for each parameter for wastewater versus soil water sample; pH will be considered first.

pH

As shown in Table III-4, the pH data for wastewater were quite variable during the two years of record. In 1969 pH remained relatively low throughout the canning season from beginning to end. In 1971 the pH started at near-neutral 7.4 and progressively deteriorated to a low reading of 4.1. This low reading is very comparable to the 1969 average reading. Comparison of the field data for soil water samples from 1969 with 1969 data on wastewater reveals that pH for soil water samples increased to near-neutral during the canning season. For 1970 soil water pH appears to be slightly basic. In 1971 pH of the soil water was slightly basic, while the pH of the wastewater was growing more and more acidic. The behavior of the soil medium in

TABLE III - 7

Chemical Data for Water Samples from Collection Tubes
(ppm except pH, E.C. and E. Coliform)

Late Cornfield Sites (9A on Figure III - 1)

Site	Date	pH	EC	DO	BOD	Coliform MPN	PO_4	NO_3	N	Na	K	Mg	Ca	CL
NE Shallow 24"	8-13-69	6.4	2290	6.7	52.0	24000	0.00			172.5	3.7	90.0	92.5	
	8-19-69	7.6	2406	3.8	76.0	20000	0.12		12.0	175.0	4.8	80.0	35.0	140.0
SE Shallow 24"	9-5-69	7.5		7.2	360.0	2000	Sample too small to analyze							
Middle Shallow 24"	8-19-69	8.0	2050	6.5	37.0	4400								
	8-28-69	7.3	1962	7.2		5000	0.00		52.8	137.9	4.5	85.0	45.0	88.4
	9-5-69	7.4	1962	7.4	257.5	5000	0.10		82.0	141.0	3.7	87.5	150.0	134.5
	9-10-69	7.2	1780	6.6	330.0		0.01		69.0	138.2	2.7	95.0	142.5	
	Mean	7.3	2075	6.5	185.4	10067	0.05		58.9	152.9	3.9	87.5	93.0	120.3
NE Deep 48"	8-13-69	6.4	2810	6.3	22.0	24000	1.26		44.5	170.0	5.6	325	180	223.0
	8-19-69	7.6	2655	6.7	34.0	12000	0.96		19.2	167.5	5.1	165	75	207.5
SE Deep 48"	8-13-69	6.3	1280	6.8	21.0	2400	0.71		23.32	68.8	8.3	50	55	
	8-19-69	7.6	1325	6.6	52.0	12000	0.00		9.8	67.3	8.5	99	43	60.5
Middle Deep 48"	8-13-69	6.6	2490	6.4	37.0	500	0.98		16.0	175.0	11.5	240	92.5	
	8-19-69	7.7	2225	6.6	68.0	2200	0.23		5.6	136.0	8.8	100	5.0	157.0
	8-28-69	7.2	1825	7.3		24000	0.15		24.0	131.4	7.9	225	140.0	152.0
	9-5-69	7.2	1862	7.2	87.5	2200	0.01		20.5	130.5	7.1	105	41.0	125.0
	9-10-69	7.0	1790	6.8	165.0					131.0	6.8	105	130.0	126.0
	Mean	7.1	2029	6.7	60.8	9913	0.54		20.4	130.8	7.7	157	84.6	150.1

Ensilage Pit Samples (see Figure III - 1)

Site	Date	pH	EC	DO	BOD	Coliform MPN	PO_4	NO_3	N	Na	K	Mg	Ca	Cl
Shallow 24"	8-19-69	3.6	2275	5.0	100.0	2000	0.00			2850	35	1410	2000	5790
	8-28/69	6.4	2080	7.3		20000	0.03		4.0	3200	40	1400	1950	6210
	9-5-69	6.3	2350	7.1	1420.0	1452	0.03			3240	45	1465	2175	5940
	9-10-69	6.3	1960	6.9	23050.0		0.03		0.7	3010	35	1520	2420	5400
	Mean	5.7	2166	6.6	8190.0	7817	0.02		2.4	3075	38	1448	2136	5835
Deep 48"	8-13-69	5.8	23000	7.0	3500.0	20000	2.80			3300	95	4020	2800	5060
	8-19-72	5.9	2550	5.4	108.0	2000	0.52			3500	60	2180	3220	4130
	8-28-69	6.5	2270	7.3		20000	0.25		4	3195	40	1930	3250	4320
	9-5-69	6.0	2220	7.2	3600.0	1320	0.36			2900	50	1960	3390	4250
	9-10-69	6.3	1980	6.8	34000.0	200	0.16			2890	28	2260	3950	3380
	Mean	6.1	6404	6.7	10302.0	8704	0.82		4	3157	54	2470	3322	4228

1970 Late Cornfield Sites (17A on Figure III - 1)

A1	8-10-70	7.9	3300											
	8-12-70	8.1	1430			9180	1.00	0.0	7.2	92.1	5.6	55.0	12	113
	8-18-70	8.1	1430			200	3.00	0.2	7.2	94.8	4.0	50.0	21	113
	8-24-70	7.1	1650				0.70	0.8	2.1	97.5	4.1	52.5	7	113
	9-5-70	7.4				40	3.70	9.0	4.9	107.0	5.1	70.0	98	105
	9-12-70						7.50	0.4	2.8	110.0	9.5	87.5	97	150
A2	8-10-70	8.1	1410				0.80		7.2	127.0	5.9	67.5	7	
	8-12-70	8.4	980			2400				115.0	4.9	50.0	14	
	8-18-70	8.3	1340			400	0.14	0.9	3.4	110.0	5.4	50.0	22	92
	9-5-70	7.7					7.50	0.1	4.2	125.0	5.5	62.5	76	86
	9-12-70							0.2	5.6	140.0	6.4	67.5	7	130
A3	8-10-70	8.0	1863				14.50		10.2				14	
	8-12-70	8.2	1550						2.8	77.2	5.1	67.5	16	
	8-18-70	8.1	2000					50.0						99
	8-24-70	7.3	2063					47.5	2.8	120.0	7.2	80.0	45	103

Site	Date	pH	EC	DO	BOD	Coliform MPN	PO_4	NO_3	N	Na	K	Mg	Ca	Cl
A1	9-5-70	7.8					0.40	34.0	7.7	105.0	6.6	87.5	83	76
	9-12-70						1.00	31.0	2.8	110.0	6.6	82.5	9	35
A4	8-10-70	7.5	2400				0.00		12.6	152.0	8.3	87.5	27	
	8-12-70	8.3	1613						5.2	107.0	7.1	60.0	63	
	8-24-70	7.3	1988					82.5	2.8	105.0	6.8	67.5	70	92
	9-5-70	7.7					0.80	30.0	4.9	97.5	6.7	65.0	98	86
	9-12-70						12.00	22.0	3.4	95.0	6.7	62.5	81	250
A3	8-10-70	8.1	1775											
	8-12-70	8.4	1490				14.00	9.5	8.8	84.1	6.7	50.0	40	57
	8-18-70	8.1						29.0						50
	8-24-70	7.1	1525					23.5	4.9	76.3	7.0	52.5	91	57
	9-5-70	7.5					0.84	0.0	2.8	76.5	7.1	52.5	90	34
	9-12-70						0.60	8.2	4.9	78.0	7.6	47.5	88	70
A6	8-10-70	8.1	1775							112.0	4.5	65.0	73	
	8-12-70	8.4	1490				1.20		4.2	98.1	4.7	60.0	27	
	8-24-70	7.3	1575				14.00	4.0	2.1	81.5	3.9	60.0	37	106
	9-5-70	7.5					0.32	0.3	4.9	90.8	4.0	62.5	99	91
	9-12-70							5.8	7.2	61.7	3.4		54	150
	Mean	7.8	1732			2444	4.00	17.0	5.2	101.6	5.9	63.8	50.6	94
B1	8-12-70	8.0	2425			20	15.00	31.0	2.1	140.0	12.0	92.5	97	106
	8-24-70	6.9	2600				0.75	112.5						113
	9-5-70						0.84	76.0	0.0	125.0	12.3	90.0	135	105
	9-12-70								3.5	117.0	11.1	87.5	110	130
B2	8-12-70	8.0	1988						13.3	115.0	7.0	82.5	73	
	8-24-70	7.2	1913			2		40.0		107.0	9.0	72.5	46	173
	9-5-70						0.80	18.5	6.7	94.8	7.2	77.5	104	96
	9-12-70						4.50	10.0	6.8	102.0	8.5	80.0	92	400

Site	Date	pH	EC	DO	BOD	Coliform MPN	PO_4	NO_3	N	Na	K	Mg	Ca	Cl
B3	8-12-70	7.9	2125					25.0		130.0	8.5	92.5	57	128
	8-18-70	8.3	1900				3.00	59.0	0.0	110.0	8.0	77.5	47	102
	8-24-70	7.3	2013			49	1.50	52.5	0.0	110.0	8.2	80.0	38	173
	9-5-70						0.90	3.5	8.8	110.0	7.5	85.0	96	86
	9-12-70						1.00	7.5	5.6	107.0	7.1	85.0	95	100
B4	8-12-70	8.0	1265					6.4	4.2	76.3	3.1	75.0	9	67
	8-18-70					20		12.0						46
	8-24-70	7.2	1390			20	1.20	11.0	4.2	62.0	3.1	67.5	14	60
	9-5-70						1.10	0.2	2.5	60.5	2.5	65.0	60	48
	9-12-70						1.50	11.4	8.4	51.0	3.0	60.0	8	150
B5	8-12-70	8.1	2050					22.0	1.8	105.0	6.3	80.0	110	127
	8-18-70	8.5	1825				1.00	69.0	8.1	86.3	5.7	62.5	68	92
	8-24-70	7.1	1975					71.3	4.2	86.3	5.0	70.0	119	100
B6	No data													
	Mean	7.7	1956			22	2.55	33.9	4.7	99.7	7.1	78.0	73	120
W1	8-10-70	7.5	995		3.6				5.6	50.0	2.9	52.5	24.0	60.0
	8-12-70	7.6	950		4.1		1.20	54.0		55.0	2.5	50.0	3.7	
	8-18-70	7.6	1130		5.4		1.50	13.0	2.8	56.6	3.0	52.5	12.0	60.0
	8-21-70	6.9	1110		5.7		0.65			60.0	2.6	55.0	11.0	
	8-24-70	6.6	1165		4.8		<0.10	12.9		62.0	2.7	60.0	7.5	64.0
	9-5-70	7.6			5.0	40	0.50	1.6	0.0	56.0	3.5	60.0	40.0	66.7
	9-12-70						0.00	5.1	4.2	58.3	3.4	62.5	40.0	90.0
W2	8-10-70	7.7	2225		4.7		1.70			102.0	11.7	72.0	107.0	
	8-12-70	7.3	1663			80	0.90	28.0		76.3	9.0	57.5	56.0	81.0
	8-18-70	7.6	1775		2.7	20	2.70	94.0	0.0	72.1	9.9	55.0	120.0	67.0
	8-21-70	6.9	1663		3.7	130	1.50			75.0	8.3	57.0	32.0	
	8-24-70	6.6	1683		3.2	110		84.2	4.2	70.4	8.2	57.5	107.0	77.0
	9-5-70	7.6			5.5	40	0.16	12.0	0.0					60.9
	9-12-70						1.80	30.0	2.1	71.8	8.0	62.5	101.0	110.0

Site	Date	pH	EC	DO	BOD	Coliform MPN	PO_4	NO_3	N	Na	K	Mg	Ca	Cl
W3	8-12-70	7.6	3100		3.1		2.70	12.5	3.5	145.0	22.2	115.0	267.0	375.0
	8-18-70	7.5	3325		2.5		1.10	118.0	2.1	135.0	17.3	115.0	248.0	368.0
	8-21-70	6.9	3200		2.4					150.0	15.0	112.0	97.0	
	8-24-70	6.6	3213		3.0		1.80	110.0		142.0	13.0	120.0	146.0	332.0
	9-5-70	7.4			5.0	40	1.24	88.0	0.0	142.0	13.4	117.0	222.0	370.0
	9-12-70						2.40	80.0	2.8	147.0	12.3	117.0	212.0	380.0
W4	8-12-70	7.5	3850		1.9	50		4.3	2.1	187.0	25.7	132.0	254.0	431.0
	8-18-70	7.7	3750		3.4		2.20	173.0	0.0	162.0	22.1	122.0	282.0	400.0
	8-21-70	7.3	3700				0.30			225.0	28.6	180.0	211.0	
	8-24-70	7.1	3850					175.0		170.0	21.0	122.0	260.0	400.0
	Mean	7.3	2353		3.9	63	1.30	60.9	2.1	107.4	11.6	87.7	124.4	210.7
1971 Late Cornfield Sites (9A on Figure III - 1)														
C1	7-16-71	8.0	1715					3.2		95.0	10.3	102	8.0	83.1
	7-27-71	8.1	1445					0.7		72.0	9.3	105	8.8	41.8
	8-17-71	7.8	1360	4.1				1.7		65.0	7.4	92	9.1	14.5
	8-19-71	7.9	1260					2.4		60.0	7.3	87	3.1	9.2
	8-23-71	7.3	1300					0.8		65.0	6.6	87	3.2	14.2
	8-25-71	8.4	1170					0.3		57.0	5.5	82	3.1	23.0
	9-11-72	7.1	1100					0.0						15.7
	9-18-71	7.7	1120					1.1						15.9
C2	7-16-71	8.2	1310					8.7		100.0	4.5	52	4.5	62.9
	7-21-72	8.4	1280					10.2		82.0	3.6	77	3.4	40.1
	8-17-71	7.7	1350	3.3				8.0		90.0	3.4	85	6.3	34.4
	8-9-71	7.9	1350					5.8		85.0	3.3	77	1.9	13.1
	8-23-71	8.0	1280					4.5		90.0	3.7	75	2.9	28.4
	8-25-71	8.4						0.5		84.0	3.2	75	1.4	36.5
	9-11-71	7.5	1370					0.9						34.7
	9-18-71	7.4	1250					4.3						36.7

Site	Date	pH	EC	DO	BOD	Coliform MPN	PO_4	NO_3	N	Na	K	Mg	Ca	Cl
C3	8-17-71	7.5	2075	2.2				50.0		127	11.4	120	58.0	84.1
	8-23-71	7.6	2075	0.1				47.0		130	10.9	115	2.8	92.3
	9-11-71	7.1	2500	6.6				70.0						226.1
	9-18-71	7.0	2200	8.8				56.2						206.6
C4	8-17-71	8.0	2250					46.0		165	11.1	145	58.0	170.0
	8-19-71	7.9	2220					40.0		160	10.2	115	27.0	141.6
	8-23-71	8.3	1800					34.0		147	8.1	107	13.0	134.9
	8-25-71	8.5	1775					21.0		132	8.0	110	8.6	135.9
	9-11-71	6.7	1700					0.2						50.4
	9-18-71	7.0	2400	7.8				2.4						8.8
C5	8-17-71	7.7	2400	2.9				7.5		127	17.2	120	77.0	158.6
	8-19-71	7.4	2200	7.9	3.6			50.0		122	15.6	122	67.0	120.0
	8-23-71	7.7	2075					54.0		150	11.4	130	19.0	131.3
	8-25-71	7.9	2100	1.3				48.7		115	10.7	127	62.0	138.1
	9-11-71	7.2	1875	6.6				3.1						119.0
	9-18-71	7.1	2450	8.5				0.9						157.7
C6	8-19-71	7.3	1800	7.9	3.5			56.0		105	14.1	67	71.0	85.2
	8-25-71	7.8	1640					53.7		105	13.3	70	68.0	111.4
	9-11-71	7.4	1560	6.6				61.5						92.1
	9-18-71	6.8	1550	8.7				57.0						88.2
	Mean	7.7	1695	5.2	3.5			23.45		105	8.8	98	24.5	82.1
1971 Barley Field Sites														
D1	7-13-71				3.2			7.2		47	4.7	20	32.0	24.7
	7-16-71	7.6	775		5.2			0.2		40	4.6	40	40.0	20.5
	7-21-71	7.3	1140		1.1			21.6		52	3.7	45	31.0	25.9
	8-23-71	7.1	2075					0.4		105	5.2	120	58.0	266.2
	8-24-71									127	11.4	92	45.0	
	8-25-71	7.4	2170					9.0		115	4.6	135	5.6	221.8

Site	Date	pH	EC	DO	BOD	Coliform MPN	PO_4	NO_3	N	Na	K	Mg	Ca	Cl
D1	9-11-71	7.0	2800					1.9						207.4
	9-18-71	7.0	3000					1.2						196.8
D2	7-16-71	7.8	600		4.3			0.7		30	1.8	30	22.0	10.2
	7-21-71	7.8	735		0.7			2.4		40	2.2	40	11.7	12.4
	8-23-71	7.6	1475					0.6		125	5.9	67	50.0	102.9
	8-25-71	7.6	1500					0.3		82	2.3	62	44.0	144.4
	9-11-71	6.9	2550					2.5						101.4
	9-18-71	6.7	1825					2.6						113.0
D3	7-16-71	7.8	830		3.8			2.7		60	1.7	40	27.0	18.5
	7-21-71	7.7	1080					19.0		52	3.7	45	31.0	33.8
	8-25-71									105	12.0	35	9.4	
D4	7-16-71	7.5	565		4.0			0.5		24.4	1.4	20	28	9.9
	8-19-71	7.8	2900					19.0		177.0	13.7	145	73	290.7
	8-23-71	8.3	1525					24.0		97.0	15.5	87	43	60.3
	8-25-71	8.1	1400					13.0		81.0	4.9	82	40	55.7
	9-11-71	7.5	1340					0.2						49.3
	9-18-71	7.4	1400					46.5						73.4
D5	8-23-71	8.3	1430					0.2		85.0	9.3	60	58	85.2
	8-25-71	8.5	1300					0.7		44.0	6.1	50	47	67.4
	9-11-71	7.5	1060					38.0						55.7
	9-18-71	7.5	1150					6.4						55.0
D6	7-16-71	7.5	2400		2.8			0.2		122	13.3	140	4.6	250.7
	7-21-71	7.3	2375		0.9			2.8		115	10.3	152	9.5	252.0
	8-19-71	8.0	2400					60.0		115	11.4	152	13.0	121.7
	8-23-71	8.4	2500					76.0		122	7.7	170	11.0	149.1
	8-25-71	8.0	2600					4.5		110	5.7	177	15.0	190.6
	9-11-71	7.1	2800					63.0						268.8
	9-18-71	7.0	2350					63.0						295.1
	Mean	7.6	1744		2.9			15.3		84	6.8	86	31.2	119.7

Research Plot

Site	Date	pH	EC	DO	BOD	Coliform MPN	PO_4	NO_3	N	Na	K	Mg	Ca	Cl
RI	8-19-71	7.8	910		3.3			13.0		62	5.8	45	22.0	8.5
	8-23-71	8.1	850					.1		57	5.1	45	2.7	21.2
	8-25-71	8.1	860					6.3		55	4.8	50	5.5	29.7
	9-11-71	7.6	700					.2						30.2
R2	8-19-71	7.7	1450		5.9			42.0		90	6.5	85	23.0	25.5
	8-23-71	8.0	1340					2.0		92	6.0	87	9.8	49.6
	8-25-71	8.0	1380					43.7		89	5.6	90	10.6	57.3
	9-11-71	7.6	1300					62.0						55.1
R3	8-19-71	No sample												
	8-23-71	8.1	1025					13.0		87	6.3	60	6.0	28.3
	8-25-71	8.1	1000					5.0		82	5.7	60	5.4	36.5
	9-11-71	7.6	870					4.0						74.0
R4	8-19-71	7.7	1360		6.1			27.0		90	8.5	85	14.0	18.1
	8-23-71	No sample												
	8-25-71	8.3	1290					23.0		83	8.0	87	4.6	50.6
	9-11-71	7.6	1300					47.5						50.5
	Mean	7.9	1117		5.1			20.6		79	6.2	89	10.4	38.2

neutralizing the acidic wastewater is satisfactory, and the cropping pattern shows little influence upon the soil's ability to neutralize the acidic wastewater. In 1971 the fields planted to late corn, and fields planted to early barley and utilized as disposal sites as fallow plots carrying no vegetive cover, neutralized the wastewater equally effectively.

Electrical Conductivity

The second parameter analyzed was electrical conductivity (EC). There is considerable variability in the data for 1969 versus 1971. In 1969 the EC was extremely high initially (August 8 was approximately the first full day of canning activity in the plant). But subsequently the EC readings showed a nearly constant level in the vicinity of 800 micromhos/cm (25°C). The 1971 data show that the highest reading occurred at the earliest date at which a sample was obtained. But in this year EC progressively diminished to the lowest reading taken on the last day of sampling, which was also 800 micromhos.

EC readings for soil water samples in 1969 showed a gradual diminishing in the reading as the canning season progressed, but soil water EC exceeded wastewater EC in all readings except the first reading for wastewater. In 1969 the average EC for soil water from the 48" tube was 2029 micromhos/cm. In 1970 EC varied noticeably with the sample site. No conclusive explanations for this variation in data are available. Possibly the most meaningful observation is the average EC for the sites installed within the field (A1-A6 and B1-B5) versus the sites installed at the bottom of the field (W1-W4). Here it is apparent that EC for bottom-field sites was significantly higher than EC for sites contained within the field. Wastewater is collected in ditches at the field bottom, and a consequent increase in percolation of wastewater through the soil column occurs. The average EC for within-field sites is 1816 micromhos; for bottom-field sites it was 2353 micromhos.

In 1971 the average EC of wastewater was 1961 micromhos. For soil water samples, the data are variable. For some sites, the minimum readings were obtained early in the canning season (D1, D2, D4, D7), while at other sites just the opposite was true (D5, C1, C2, C4, C6). Possibly the fact that one field (D1-D7) was planted to barley and wastewater was applied to a soil bare of vegetative cover and the other field (C1-C6) employed a cover of late corn during the cycle of irrigation with wastewater explains the conflict in data. Nevertheless, average values for EC of soil water for both fields are lower than average values of EC for the wastewater (1596 and 1695 versus 1961). Apart from these observations for different years in comparison of EC for wastewater versus soil water, it is not possible to state conclusively whether or not the soil column is acting as a renovation medium in reducing EC of the wastewater.

BOD

The next parameter was biological oxygen demand (BOD). For this parameter there is no equivocation that the soil column functioned admirably in renovating the wastewater. The wastewater BOD was so high that its precise value was never satisfactorily determined, but it was in excess of 17,000 ppm. For soil water samples, BOD ranged from an average of 60.8 ppm for the 48" tensiometer in 1969 to a low of 2.7 ppm for the sites D1-D7 of 1971.

Coliform

Neither is there any uncertainty in the coliform data. Most probable number (mpn) values for coliform were obtained for wastewater samples and for soil water samples. In all cases the mpn for wastewater was high (greater than 240×10^6) while mpn for soil water samples varied from a high of 24,000 to many samples showing no coliform present. In addition, in nearly all wastewater samples the presence of fecal coliform was verified. For soil water samples, in no case were fecal coliform detected in the sample.

Phosphate

Considerable difficulty was experienced in achieving similar results for the same sample in several runs of PO_4 analysis. Consequently, the range of error must be considered large in these data. For this reason, only limited value is placed on the results. Illustratively, for 1969 phosphate levels were generally higher for samples taken from the 48" depth than for samples taken from the 24" depth. This is counter to all evidence relative to phosphate renovation occurring with the soil column as reported in the literature on this subject. An examination of average concentrations shows 4.93 ppm PO_4 in wastewater and a range of .54 to 4.00 ppm PO_4 in soil water samples. The only conclusion we draw is that in general there is some reduction in the concentration of PO_4 as the wastewater percolates through the soil column.

Nitrate

Nitrate in the wastewater varied from 350 ppm on August 8 and 9 of 1971 to only 1.2 ppm for August 17 and 24. In general, the wastewater had only a modest amount of NO_3. For soil water samples in 1970, nitrate levels varied widely with the site, and with the date of sampling. In general, nitrate levels in soil water for sites A1-A6 showed the lowest concentrations, with an average of 16.95 ppm. Sites B1-B5 showed an average of 33.62 ppm NO_3, while the sites at the bottom of the field (W1-W4) gave the highest readings with an average of 60.9 ppm. This higher average for bottom-field sites is to be expected since it is here that percolation of wastewater through the soil column is maximized because of the concentration of wastewater in collection ditches at the end of the field. These values for nitrates in soil water are high. Such high concentrations of nitrates could present potential problems in deterioration of ground-water quality if the nitrates were transported downward by percolating soil water.

Chloride

In the wastewater the chloride concentration averaged 112 ppm during 1969. In 1971 the average was 419 ppm when the extremely high value for August 9 is included. Excluding August 9 data, the chloride concentration averaged 243 ppm. For soil water samples in 1969, the concentration of the chloride ion was 150 ppm at the 48" depth. In 1970 the average for soil water samples dropped to 94 ppm chloride for sites A1-A6, 120 ppm for B1-B5, and 211 ppm for W1-W4. Here again, the effect of concentrating the wastewater in collection ditches at the end of the field (W1-W4) is apparent.

Metal Ions

For the metal ions of sodium, magnesium, potassium, and calcium, sodium is of special interest in that the concentration of sodium is an indicator of the relative potential soil quality deterioration resulting from the disposal of wastewater at the site. The concentration of sodium in the wastewater in 1969, excluding the one reading for the August 8 sample, was 91 ppm sodium. In 1971 the sodium concentration averaged 339 ppm in wastewater. Comparing 1969 soil water samples to 1969 wastewater, the concentration of sodium is higher in soil water samples, averaging 131 ppm in the 48" tensiometers. For 1970, soil water sodium concentrations varied from 102 ppm for A1-A6, to 100 ppm for B1-B5, to 107 ppm for W1-W4. In 1971, when sodium concentrations averaged 339 ppm in the wastewater, the sodium concentration averaged 105 ppm for all sites. There is little change in the relative concentrations of sodium in the soil water samples from year to year, even though the relative concentration of sodium in the wastewater appears to be quite variable.

Soil Water Samples from Non-Disposal Fields

Finally, an examination of soil water from the research plot shown in Figure III-1 was utilized to determine whether or not there was any difference in quality between soil water from fields irrigated with wastewater versus fields irrigated with ordinary ditch water. Chemical data for soil water samples from the research plot are presented in Table III-7. The research plot has never been irrigated with wastewater, and only commercial fertilizers have been utilized in promoting crop growth. The plot is utilized in the Green Giant Company program of crop research in corn varieties for growing on company-contracted farms. A comparison of pH shows no significant difference between disposal field and research plot in soil water samples. For EC, there is a significant difference, with the EC of the research plots averaging only 1117 and for disposal fields averaging 1744 and 1695 for the same year (1971). Unusually enough, the average BOD of the research plot exceeded the average for the two disposal fields in 1971, but because of limited sample size from the tubes, only a few samples were available for analysis, so no strong conclusions can be drawn. Nitrates averaged 15.23 ppm for the barley field, and 23.45 ppm for the late cornfield in 1971. For the research plot, nitrates averaged 20.6, showing little difference between disposal fields and research plot. Sodium concentrations and the concentration of chlorides for disposal fields were significantly higher than in the research plot, showing that there was greater salinity hazard associated with the wastewater than with the normal ditch water (see Table III-7 for means).

Ground-Water Quality

Factors in Infiltration

Several factors affecting the efficiency with which the wastewater is absorbed into the soil surface have forced Green Giant to adopt a strict regime for their irrigation scheduling in wastewater-irrigated fields. Firstly, the rate of infiltration of irrigation water into the soil is quite low. A one-inch siphon tube delivering water from the ditch at the head of the field delivers enough water to provide a delivery of water to the field bottom 1200 feet away in less than twelve hours of irrigation time. In a lighter soil it can easily require four such siphons to deliver water to the bottom of a 1200 foot field.

As a consequence of this slow rate of infiltration, Green Giant employs an irrigator full-time to tend to fields utilized in the disposal program. As soon as the wastewater reaches the end of the field it is necessary to cut the flow of water into the corrugate. Even so, some water collects at the field bottom as runoff, and this water is channeled into a series of collection ditches plowed diagonally across the corrugates at the bottom of the field. One collection ditch will intercept three to six corrugates. The collection ditches are approximately 18 inches deep and 36 inches wide. Sample collection sites W1-W4 reflect the relative quality of soil water obtained from the field bottom adjacent to these collection ditches. It is apparent that the potential for recharge of wastewater to the water table is maximized at the field bottom. It is also apparent that the quality of the soil water is lower here than at sites within the field.

A second factor which explains the limited infiltration is the steep slope found in the larger of the two fields depicted in Figure III-1. This slope (approximately 2-1/2°) results in a relatively fast rate of flow of wastewater from top of field to field bottom. A third item is the relatively shallow depth of unconsolidated material overlying the basalt bedrock. Because of the general lack of adequate depth of soil it is necessary that the volume of runoff water allowed to collect in the diagonal ditches at field bottom be kept to a minimum. These ditches, being plowed a depth of 18 inches or more, reduce even more the height of soil column available for a renovative medium.

Runoff Retention for Infiltration

In order to minimize problems with surplus runoff, Green Giant restricts the actual amount of wastewater applied to any one field. In 1970 a Parshall flume was installed in the ditch leading to the larger field (Figure III-1, 17-A). Only 11.26 acre-feet of water were applied to the field in the interval July 12-September 20, as measured by a recorder fixed to the flume. Green Giant can achieve this minimum rate of application (less than an acre-foot of wastewater per acre of disposal site) because it enjoys an abundance of land. The company farm and adjacent private land leased by Green Giant totals 145 acres. The plant utilizes approximately 1,000,000 gallons of water per day, and the bulk of this is discharged from the plant as wastewater. For a 45-day canning season, this amounts to less than 138 acre-feet of wastewater to apply to the farmed land.

Evaluation of Recharge of Ground Water by Percolating Wastewater

The quality of soil water obtained from the instrument sites showed that some constituents, particularly nitrates, offered some threat to ground-water quality if allowed to percolate into the ground-water supply. As a consequence, an evaluation of the recharge of ground water by percolating wastewater was attempted. This phase of the investigation involved two separate activities.

The first was a monitoring program for detecting changes in soil moisture. Troxler neutron probe aluminum access tubes were installed adjacent to each soil water sample site reaching as close to bedrock depth as drilling permitted. Thirty-second readings were taken at six-inch intervals, beginning at the six-inch depth and proceeding by steps to hole bottom. These data are charted and presented in graphs; and in addition, a program was utilized at the ARS Snake River Conservation Research Center computer facility, Kimberly, Idaho, to calculate the change in available moisture. The data are voluminous and, therefore, are not presented in this report. The data show that as growing season progresses there is a gradual dewatering of the soil profile in fields planted to late corn. In other words, there is an insufficient amount of water applied in the wastewater irrigation program to maintain steady state conditions for soil moisture within the soil profile. Therefore, no recharge occurs in these fields. In the early barley fields the data show another picture.

Once the Green Giant field crews have harvested the barley crop, the field is trenched with deeply plowed corrugates of the same dimensions as the collection ditches referred to earlier (18" deep by 36" wide). Wastewater is applied to these corrugates from the distribution ditch at the head of the field, and the program is monitored by the irrigator to guarantee that the flow of wastewater to any one corrugate is shut off before the flow reaches the end of the field. The field bottom is also trenched diagonally to intercept any runoff flow. During irrigation in the larger 17-acre field in 1971, not once did the wastewater reach the end of the field. In only one instance did the water reach the middle of the field. Admittedly, only a limited amount of wastewater was applied to the field (less than seven acre feet), but the rate of infiltration was much greater with the deeply trenched corrugates than with the shallow corrugates utilized with cropped fields. The access tubes contained standing water (indicating saturation) wherever wastewater reached the location of the tube in the field. Consequently, recharge by percolating wastewater must have occurred in these fields planted to early barley and subsequently harvested and trenched for use in the wastewater disposal program. Whether water from this zone of saturation reached the regional water table or flowed laterally along the bedrock surface to an irrigation ditch is impossible to ascertain.

A third phase of the Green Giant program was also investigated. This phase involved the monitoring of the ensilage disposal operation. The area of the ensilage disposal site is illustrated in Figure III-1. The Green Giant Company collects all solid wastes (corn husks, cobs, kernels, etc.) at appropriate points within the plant, and these solids are transported by overhead conveyor to a field area. Here the solids are distributed by machinery (tractor-drawn manure spreaders) over the surface of the field. The field is underlain with drain tiles, and the percolate from the pile of ensilage is intercepted by the drain tile and fed into a sump. An irrigation pump lifts the percolate and delivers the percolate to the ensilage disposal site shown in Figure III-1. Here the percolate is delivered to the terrestrial disposal site (approximately two acres) into deeply trenched corrugates of the same dimensions described earlier (18" by 36"). There is no transpiration from the field. The ensilage percolate is of very poor quality (see Table III-4), and the soil water samples from the paired 24" and 48" deep collection tubes show little renovation. We were unable to measure the disposal rate, but it is overwhelmingly greater (per unit area basis) than any other disposal operation practiced. Disposal of the ensilage drainage constitutes the most significant potential ground-water pollution hazard in the operation.

The last phase of the investigation of recharge by wastewater involved monitoring local domestic wells to determine whether there were problems with ground-water quality down gradient from the Green Giant disposal sites. Table

III-8 presents a summary of data for domestic water well samples from sites shown in Figure III-1. The wells are located between the wastewater reuse area and the main ground-water discharge area for the region. Only one well (No. 5) reflected any problem with water quality. In well 5 nitrate concentrations were slightly higher than generally is desirable according to U. S. Public Health standards. Overall, water quality of these wells is not greatly different from ground water from the entire Snake River Plain.

Crop Yields in Fields Irrigated with Wastewater

Corn yields from land irrigated with wastewater average 7.7 tons per acre. This compares favorably with a national average of 6.7 tons per acre, but it is noteworthy that Green Giant averages up to 10.5 tons per acre on private plots in the Buhl area apart from the waste disposal sites. So there is a lesser yield from land used for the disposal of wastewater. This lesser yield is explained partly by the necessity of disturbing the cropped area at field bottom when the diagonal collection ditches are constructed, partly by the fact that an inadequate amount of irrigation water is applied to the fields and partly by the fact that the normal $12 to $22 of commercial fertilizer customarily applied to fields is not applied to the disposal fields. The company realizes a savings in fertilizer of between $12 to $22 per acre, and it still realizes a crop yield greater than the average for Green Giant corn operations across the country; it also achieves economical disposal and a degree of renovation of its wastewater. Barley yields average 120-150 bushels per acre on these same fields. No commercial fertilizer is applied, so the crop is benefiting from residual nutrients made available from the previous year's application of wastewater.

Recommendations

Since domestic well data show no problems with ground-water quality, overall, the Green giant wastewater disposal program must be considered as an effective

TABLE III - 8

Domestic Well Samples (see Figure III - 1)

Well	Date	pH	EC	DO	BOD	Coliform MNP	PO_4	NO_3	N	Na	K	Mg	Ca	Cl
Wagner - 1	8-19-71	7.6	1160		2.1			4.1		137	11.0	35.0	33.0	46.0
	8-25-71	7.9	1160		0.0			0.1		147	10.0	35.0	15.0	76.1
	9-4-71		1060		0.0			4.0						57.7
	9-11-71	7.3	1100		0.0			3.4						64.3
	9-18-71	7.2	1020		0.0			4.2		137	11.0	35.0	33.0	65.2
P. Duffy - 2	8-28-69		940		0.0	2	0.00	3.8		104	8.4	42.4	41.1	68.0
	9-10-69	7.2	965		0.0	2	.25	3.7		110	8.8	43.8	42.0	
	9-22-69	7.5	935		0.0	0	.01	0.0		112	8.6	48.2	46.0	71.0
	9-5-70	7.4			0.0	1100*	.80	3.2	1.8	110	11.0	45.0	62.0	57.6
	8-19-71	7.5	1200		2.1	0		4.6						54.5
	8-25-71	7.8	1180		0.0			3.7		105	8.3	45.0	23.0	77.1
	9-4-71		975	3.7	0.0			4.3						60.4
	9-11-71	7.5	1040		0.0									
	9-18-71	7.3	1040		0.0			2.7						63.6
Wetsteen - 3	8-28-69		929		0.0	2	.03	0.5		93	48.0	16.5	16.5	61.5
	9-10-69	7.1	1080	6.0	12.0	2	.01	0.3		99	6.2	51.0	25.8	
	9-22-69	7.5	1055		0.0	5	.10			138	6.2	50.0	37.0	
	9-5-70	7.4			0.0	21	.10	0.4		98	6.8	55.0	74.0	67.2
	8-19-71	7.5	1300		2.8			2.4		102	7.2	52.0	6.4	70.4
	8-25-71	7.8	1220		0.0			1.1		102	6.3	55.0	4.1	94.1
	9-4-71		1125	1.3	0.0			1.3						73.5
	9-11-71	7.4	1140		0.0			1.2						83.6
	9-18-71	7.3	1160		0.0			2.0						83.2
Caughey - 4	8-28-69		869		0.0	0	2.10	0.0	4.6	104	7.7	44.1	39.0	61.5
	9-10-69	7.1	958	6.5	2.0	0	0.50	0.0	4.5	109	7.7	45.0	40.0	
	9-22-69	7.3	931		0.0	0	15.00	0.0	3.2	162	7.7	43.8	39.3	65.0
	9-5-70	7.4			0.0	0	40.00	0.1	1.2	103	8.7	50.2	59.0	57.6

* Not counted in mean

Well	Date	pH	EC	DO	BOD	Coliform MNP	PO_3	NO_4	N	Na	K	Mg	Ca	Cl
Caughey - 4	8-19-71	7.5	1160		1.9			2.9						67.6
	8-25-71	7.8	1215		0.0			1.8		105	7.9	50.0	25.0	87.0
	9-4-71		1060	1.2	0.0			2.6						66.1
	9-11-71	7.4	1030		0.0									
	9-18-71	6.9	1040		0.0			2.0						76.7
Likeness - 5	8-28-69		902		0.0	2		6.9		138	5.8	50.0	41.6	106.5
	9-10-69	7.2	1050	7.2	2.4	2	.06	8.4		135	5.9	47.4	39.3	
	9-22-69	7.4	1025		0.0	2	.02	7.0		128	5.6	45.4	33.5	
	9-5-70	7.4			0.0	0	.00	5.4		137	6.5	52.5	57.0	86.4
	8-19-71	7.6	1250		1.9			6.0		125	5.1	50.0	35.0	64.7
	9-4-71		985		0.0									
	9-11-71	7.5	1040		0.0			5.7						74.0
	9-18-71	7.1	1000		0.0			9.8						70.4
Hatfield - 6	9-5-70	7.6				0	.60	4.0	0.0	110	7.7	37.5	41.0	48.0
	8-19-71	8.6	1140	1.7	0.0			6.1		270	9.4	1.1	0.5	41.7
	8-25-71	8.1	1080		0.0			4.3		252	8.8	0.5	0.5	55.9
	9-4-71		985		0.0									
	9-11-71	7.6	950		0.0			4.5						51.0
	9-18-71	7.7	975		0.0			3.2						44.8
Watson - 7	8-25-71	7.9	1030					4.2		122	7.6	40.0	4.9	60.1
	9-4-71		905											
	9-11-71	7.5	980					3.5						44.3
	9-18-71	7.3	1120					3.9						45.0
H. Duffy - 8	9-5-70	7.6				0	.20	4.2	2.1	135	7.3	42.5	47.0	48.0
	8-19-71	7.7	1140	2.1	0.0			5.5		125	6.5	40.0	31.0	44.2
	8-25-71	8.0	1260		0.0			4.5		140	7.0	45.0	2.3	67.9
	9-4-71		1000	5.7	0.0			5.6		132	6.3	40.0	28.0	56.7
	9-11-71	7.6	1010		0.0			4.6						62.9
	9-18-71	7.5	1020		0.0			4.8						61.7
	Mean	7.5	1058	3.7	0.5	2	0.17	3.5	2.5	129	9.0	42.0	32.0	64.6

means of disposing of industrial wastewater. However, several steps could be taken which would preclude potential future deterioration of ground-water quality in the vicinity of the disposal site. Firstly, alternative methods should be devised to replace the application of ensilage drainage to the deeply trenched ensilage disposal site. An alternative means for treatment of this wastewater might be to contract with the City of Buhl for disposal in the city sewage treatment system.

Secondly, the discontinuance of the irrigation of fallow fields plowed in deep corrugate should be considered. If no suitable crop (such as a grass) can be grown during the period of irrigation, then at least only a normal irrigation corrugate should be used to distribute the wastewater over a larger area of the field in order to utilize more effectively the soil column for renovation and to inhibit the recharge of wastewater to the water table.

Thirdly, runoff wastewater should not be allowed to stand in collection ditches at field bottom. An alternative would be to employ a recirculating irrigation system similar to those designed at the Snake River Conservation Research Center in Kimberly, Idaho. Reuse of runoff water would improve water-application efficiency. Such a system would employ pumps to return the runoff back to the head of the field for rechanneling into the ditch. This would promote greater crop production from the field as well as alleviate the problem of recharge of wastewater toward the water table at the lower end of the field.

Green Giant employs an early season practice of massive early irrigation in order to provide adequate water for the growth of corn on fields to be used in the wastewater disposal program. This massive pre-irrigation commences customarily in the second week of June, and water is continuously applied to the fields for eight to ten days. There is massive runoff, and it is estimated that only 25% of the water applied is retained within the soil column. This practice of preseason irrigation does serve to alleviate the long-term salinity hazard associated with the irrigation of strongly saline wastewater. Salts that are residual from the wastewater reuse season are undoubtedly leached from the field by this process.

If the three recommendations suggested by the investigators are implemented, the terrestrial disposal program should serve as a model to industry for the responsible handling of industrial wastes.

CHAPTER IV
CHEMICAL INTERACTIONS OF WASTEWATER IN A SOIL ENVIRONMENT

Introduction

Chapter IV deals with the ability of the soil column discussed in Chapter III to handle sweet corn process wastewater under conditions of extreme loading.

Corn processing wastes contain a large amount of organic matter both in suspension and in solution. If this material is dumped into surface supply of water, it will soon use up the available oxygen supply of the stream, causing septic conditions. The chemical oxygen demand of the corn wastewater which has been used in this study ranges from 1300 to 4600 ppm.

Increasing amounts of wastewater are being used in irrigation or in land disposal operations. Spray irrigation (SI), rapid infiltration (RI), and overland runoff (OR) are the three types of methods being used in irrigation with the spray system being the most common. Irrigation with wastewater has its limitations, both physical and economical; of primary importance is the availability of suitable land within a short distance of the wastewater source. As stated previously, other factors enter the picture such as the porosity of the soil, the purpose for which the land is to be utilized (cattle grazing, crop production, or simply waste disposal), and topography. Climatic conditions and hydrological factors affect the choice of irrigation although to a lesser degree than the above mentioned factors.

In agricultural irrigation the objective is to supply the minimum water required to produce maximum crop production; in waste disposal the objective is to apply the maximum amount of wastewater which can be absorbed without surface runoff or damage to the cover crop or the ground water.

In this study the second objective was investigated along with those materials in wastewater which have the greatest effects on agricultural irrigation; these are pH, COD, P, N_2, Na, K, Ca, and Mg.

Chemical Interactions of Wastewater in Soil

In order to predict the effectiveness of soil systems in removing chemicals from applied wastewater and to determine the chemical changes in soil properties resulting from percolation of wastewater, it is necessary to know the components in the soil which participate in chemical processes and the nature of these processes.

Soil Components Active in Chemical Processes

Regardless of the different kinds of soils, a sample of any soil can be considered as containing inorganic solids, organic solids, solution, and vapor. A typical mineral soil (the most common soil) may contain about 45% inorganic solids and from 2% to 8% organic matter. The solution contains a vast variety of dissolved inorganic substances, soluble organic compounds, and dissolved gases. The most important gas is CO_2 which may convert to HCO_3^- which determines soil acidity.

The vapor phase contains N_2, O_2, CO_2, H_2O, and many other gases. The importance of the vapor phase in wastewater treatment lies primarily in utilization of management practices which provide good soil aeration so that the composition of the soil air remains suitable for providing biological interactions with wastewater chemicals and in providing a pathway for release of volatile chemicals and metabolic by-products into the atmosphere.

The soil participates in chemical processes such as precipitation of insoluble compounds, formation of soluble inorganic-organic chelates, ion exchange, and ion adsorption. Microbiological processes in the soil require dissolved chemicals and uptake of wastewater chemicals by plants from the solution phase.

The inorganic solid fraction of the soil is mineralogically and chemically complex. It may be characterized according to particle diameter into sand (2.00 - 0.02 mm), silt (0.02 - 0.002 mm), and clay (<0.002 mm) fractions. The sand and silt fractions are composed mostly of primary minerals like quartz (SiO_2), feldspars ($KAlSi_3O_8$, $NaAlSi_3O_8$, $CaAl_2Si_2O_8$), pyroxenes [(Ca, Mg, $Fe_1Al)(SiAl)_2O_6$], amphiboles ($Ca_2(Mg, Fe)_5$, $Si_8O_{22}(OH)_2$), and olivines [$(Mg, Fe)_2\ SiO_4$], as silicate, calcium, magnesium, and iron carbonate ($CaCO_3$, $MgCO_3$, $FeCO_3$), gypsum ($CaSO_4$), and pyrite (FeS) as nonsilicate. Actually most of the elements present in wastewater, if not all of them, are found in the solid fraction of the soil. However, the elements are found in soluble form in wastewater or become soluble by biodegradation processes. By contrast, they are normally found in insoluble form in the soil.

The clay fraction of the soil has higher surface area than all the other fractions and it has the greatest number of adsorption sites. For laboratory research on short term renovation, clays have considerable importance because most of the materials in the clay fraction have either a permanent negative charge countered by exchangeable cations, or possess a charge dependent on the pH of the soil solution which influences the retention of both cations and anions as a function of pH. Micas, illites, and vermiculites affect the ability of soil to retain NH_4^+ in wastewater. Montmorillonite-type minerals which expand upon wetting may cause reduction in the water permeability of soil when Na^+ in wastewater becomes the dominant type of exchangeable cation. These minerals can be expected to adsorb heavy metal cations from wastewater applied to the soil. Kaolinite and halloysite are not so important because of their less specific area and exchange capacities. Aluminum hydroxide ($Al(OH)_3$) and iron hydroxide ($Fe(OH)_3$) are very important in determining the ability of soils to assimilate wastewater chemicals present in anionic form such as phosphates. Unfortunately, the minerals with high ion exchange capacity are also the minerals which disperse when exposed to high concentrations of sodium.

The organic fraction of the soil may range from completely undecomposed plant litter to individual organic molecules. Lignins, fats, oils, resins, cellulose, starches, and proteins are among the components of the organic fraction. Some of these components are resistant to rapid microbial degradation; others are degraded to simpler compounds like amino acids, amides, alcohols, aldehydes, ketones, and low molecular weight acids. Decomposition may go further to CO_2, H_2), NO_3^-, and $SO_4^{=}$'s. Organic matter has a higher cation exchange capacity than minerals and heavy metal cations normally are absorbed by organic matter which reduces mobility of these chemicals in soils.

The Nature of Chemical Processes in Soil

The availability of a soil to renovate wastewater is governed by many chemical and biochemical processes. The most important chemical processes are:

Ion Exchange

In ion exchange specific ions in water are exchanged for complementary ions that are part of the complex of a solid exchange medium. Ion exchange is the most common chemical process which occurs in soils. This process depends on the clay part of the inorganic fraction and the organic fraction of the soil. Layer aluminum silicate minerals in the clay fraction are largely responsible for the cation exchange capacity of the inorganic fraction of the soil. The cation exchange property is due to the permanent negative charge within the mineral crystals lattice possessed by these minerals. The negative lattice charge must be neutralized by positive ions and so the operation takes place. The cation exchange capacity (CEC) in the soil is equivalent to the amount of the exchangeable cations associated with the various types of mineral surfaces which have a negative charge. Conventionally, the CEC is expressed as milliequivalents of exchangeable cations per 100 grams of the soil and for soil minerals it ranges from 100 meq./100 gr for montmorillonite to 5 meq./100 gr for kaolinite type minerals.

Another type of ion exchange reflected in the retention of both cation and anions is possessed by the mineral fraction of soil and it depends upon the acidity or the pH of the soil. It is thought that this type of ion exchange is resulting as a consequence of the dissociation or association of hydrogen ions (H^+) with structural elements at the crystal edges of the more amorphose aluminum silicate minerals and with aluminum and iron hydroxides. This type of ion exchange is important in pH values more than 7 and less than 5, and it may be 10 to 20% of the total ion exchange capacity. It does account for the tendency of soils to retain anions with decreasing pH and, in part, for the increase in cation exchange capacity with increasing pH.

Other than the types and amounts of minerals in the clay fraction and soil pH, the cation exchange characteristics of soils depend upon the nature and amount of organic matter in soil.

Although cation exchange capacity is an important factor affecting the ability of the soil to remove cations from a solution by the inorganic and organic components adsorption, this does not mean that the chemical removing capacity of the soil is equal to the CEC of this soil. The removal of wastewater chemicals by the soil is accompanied by the release of Ca^{++} and Na^+ because the exchange capacity of the soil is normally already saturated with such cations. Wastewater itself normally contains large amounts of Na^+ and Ca^{++} relative to the amounts of other heavy metals. So, the removal of heavy metal cations from wastewater by CEC may be limited by the competing effects of the common cations present.

Adsorption of Dissolved Constituents from Soil Solution

In general, the adsorption process can be represented by the following equilibrium:

$$\text{Insoluble-x} \leftarrow \text{Adsorbed-x} \rightleftarrows \text{Soluble-x}$$

where x represents the component adsorbed from solution. Adsorption is normally quite rapid in the soil, and the component adsorbed tends to equilibrate with the solution phase.

Precipitation

In precipitation, dissolved substances are thrown out of solution. If the cations and anions concentrations in the soil solution become high, association between specific types of them may occur to form solid chemical compounds with a limited solubility.

Oxidation/Reduction

Most oxidation/reduction reactions which occur in soil are biochemical reactions. They are directly or indirectly related to the processes by which microorganisms degrade organic matter in the soil or in the wastewater applied to it. Although oxygen is involved in many oxidation/reduction reactions, under unaerobic conditions microorganisms which obtain their energy from oxidizing organic matter utilizing oxygen must find a substitute for O_2 in metabolic process. Among these substitutes for O_2 are: nitrogen, sulfur, iron, and manganese. The chemistry of these elements varies according to whether they are present in oxidized or reduced form. For example, (NO_3^-) N_2 in soils is freely mobile but it can be immobilized by cation exchange and adsorption processes. Fe^{3+} is immobile in soil while Fe^{2+} is relatively soluble. So, the oxidation/reduction process is important in determining the chemical properties of certain types of chemicals.

Soluble Organic Chelates

This process is the combining of organic chemicals with metal ions which results in soluble but non-ionic forms. Here the organic chemicals do not increase the ability of the soil to retain ions.

Fate of Wastewater Chemicals Applied to Land

Information relevant to understanding the general behavior of wastewater chemicals in soil is considerably limited.

As was previously mentioned, the ability of soil to retain wastewater chemicals is related to the textural characteristics of the soil. But because of inadequate directly applicable data, prediction as to the efficiency of removal of chemicals from wastewater by soil must be primarily a judgment synthesized from the limited amount of the various types of information available.

Methods and Procedures

In order to study the mobility and retention of wastewater chemicals in soil, many investigators have used the laboratory rather than the field because laboratory techniques have a higher degree of control and precision. However, it may be difficult to translate the laboratory results into quantitative terms to the practical field situations because of the profound influence of short term phenomena. Laboratory techniques were used in this study, and this report should be viewed with this consideration in mind.

Procedures

The sampling sites from where the samples used in this study were taken are located in the fields discussed in Chapter III. Standard Shelby tube sampling practices were used to obtain the six soil columns discussed in this chapter.

Three of the six soil samples (columns) were mounted in such a way to make it possible to feed the soil with wastewater from the top and collect the effluent samples from the bottom. Before mounting, it was thought that samples from different depths of the soil column would be available, but samples were very difficult to obtain except from the bottom of the columns. As a result, and because of the importance of the first foot of the soil (it contains most of the soil microorganisms), the other three soil columns were cut to one foot lengths and treated in the same manner as the others were treated.

For safety before the beginning of the feeding operation, the soil columns were seeded with 100 ml each from a bacteria culture.

Wastewater Analysis

Wastewater samples from the sweet corn processing plant near Buhl, Idaho, were filtered through glass wool. The filtrate was applied to the soil columns after it was analyzed for COD, pH, NO_3^-, NH_4^+, Organic N, $PO_4^{\equiv}$, K^+, Na^+, Ca^{++}, and Mg^{++}. Standard methods were used in the analyses of all the parameters (Standard Methods for the Examination of Water and Wastewater, 1971, 18th edition, American Public Health Association, Washington, D.C.).

Effluent Sample Analyses

One sample was collected from the bottom of each column every day. In each sample the values of the parameter which were determined in the original wastewater were determined using standard methods (cited above).

Soil Sample Analyses

Two soil samples were collected from each soil column (one from the top and the other from the bottom) before and after treatment with wastewater. The following parameters were determined in each sample:

pH

The pH of each sample was determined by mixing 1 gm of soil with 10 ml of distilled water and reading the pH of the suspension directly from the pH meter.

Cation Exchange capacity (CEC)

To determine this parameter calcium at a neutral pH was used. Refer to Appendix A.

Extractable Metallic Cations

Neutral NH_4OA_c was used in determing EMC. Refer to Appendix B.

Organic Matter

The method for determination of the OM is described in Appendix C.

Soil Nitrate Nitrogen (NO_3^-N)

The method shown in Appendix D was used in determining NO_3^-N.

0.5 M $NaHCO_3$ Extractable Phosphorus

See Appendix E.

Air-dried soil was used in all determinations.

Results and Discussion

Wastewater and Effluent Analyses

In Table IV-1, the analyses of the four wastewater samples applied to the soil are tabulated. Samples w_1, w_2, and w_3 were used to feed Columns B2, B5, and B6. The first sample (w_1) was applied to the three columns from the beginning to August 5, 1971, and the second sample (w_2) was from August 5, 1971 to August 15, 1971, and the third sample from August 15, 1971 to the end of the feeding operation. The fourth sample (w_4) was used in feeding Columns B1, B3, and B4. Physically, the effluent had no odor, no color, and it was tasteless.

The flow rate is written on each table.

Soil Analyses

A combined sample was taken from the six columns and analyzed for moisture content, water-holding capacity, pH, bacteria counts, fungi counts, and actimonysites counts in the soil microbiology laboratory. The following results were observed: 5.3%, 50.45, 8.1, 1.32×10^7, 1.09×10^5, and 5.4×10^6 for each of the above parameters, respectively. The soil in general was classified to be silt-loam.

Tables IV-8 and IV-9 show the soil analyses results for each sample before and after treatment with wastewater.

Physical Properties of the Effluent

In all of the percolate (effluent) samples the water was clear, odorless, and without any unpleasant taste. The results of all analyses are shown in Tables IV-2 through IV-7.

H^+

The pH of the wastewater in the four wastewater samples used in this study was between 3.45 and 5.80. All the percolate samples had neutral pH (7.20-8.70). The soil reacted with the wastewater to decrease the hydrogen in concentration.

Organic Matter

The organic matter was estimated by the chemical oxygen demand (COD) which provides a measure of the oxygen equivalent of that portion of the organic matter in a sample that is susceptible to oxidation by a strong chemical oxidant. The reason the COD was used in place of biochemical oxygen demand is because the COD test is simple, rapid, gives reproducible results, and it measures the concentration of all organic material as opposed to that which is biodegradable.

As shown in Tables IV-2 to IV-7, the COD value was decreased by 97% in the beginning of the feeding operation and by 100% after 25 days of feeding or after applying 3.5 liters of waste to the soil columns of 2.5 to 3.75 feet depth. These results are very close to Heywood, et al. (1969) results which are 96-98% lowering of the COD.

In the percolate from the three one-foot depth soil columns, the COD value reached zero after 6, 7, and 24 days and after 0.72, 0.87, and 1.1 liters of waste were applied.

Nitrogen

Ammonia nitrogen was almost completely removed from the wastewater applied to the soil. Ammonia nitrogen values were less than 1 ppm in all percolate samples. The ammonia is undoubtedly converted by the soil microorganisms to nitrites and finally to nitrate, hence the reason that the nitrate values decreased in the beginning of the feeding (percolation) operation. The organic nitrogen was removed from the wastewater by 30% to 70%. This is also due to the nitrification processes.

Nitrate values showed an increase up to 240 ppm from less than 1 ppm in the beginning; they then decreased to zero. The increase may have been due to nitrification processes and mainly to the soluble nitrates in the soil.

Phosphates

The phosphates were completely removed from the wastewater. This may have been due to isomorphous replacement of hydroxyl ions in the clay lattices or to biological removal of dissolved phosphates in the area of concentrated biological activity. The biological activity is probably the most important factor in phosphates retention but adsorption may have played a role also.

Potassium

The changes in K^+ values with the waste volume applied are tabulated in Tables IV-2 through IV-7. There was a considerable decrease in K^+ values from the first percolate sample. About 95% of the K^+ in the waste was removed. Adsorption and other cation exchange reactions are responsible for the K^+ retention.

Na^+, Ca^{++}, and Mg^{++}

The Na^+ values remained about constant except for some increase in one or two columns and some decrease in one column. It was observed that the increase happened in columns of one-foot length which may be due to leaching from the soil. On the other hand, the decrease was observed in the first seven percolate samples collected from Column B5 (3.75 ft.), which makes the effect of length of column questionable.

It is difficult to draw conclusions for Ca^{++} and Mg^{++} because both of them are variable in concentration. An increase in some samples and a decrease in others were observed, but it can be stated that there was a small increase in the Mg^{++} and an increase and a decrease in Ca^{++}. These results may be due to cation exchange processes which were affected by inhomogeneous materials.

Calculation of Organic Removal

The tabulation below shows the calculated results of organic removals of COD.

Column Number	Volume of Soil (cm^3)	Volume of Waste Applied (ml)	Amount of COD Applied (mg)	Amount of COD Removed (mg)	Amount of COD Removed (Mg/cm^3 Soil)
B1	1728.70	1252	4,507.2	4,433.28	2.564
B2	4321.76	10774	31,885.8	31,362.87	7.257
B3	1728.70	1977	7,117.2	7,000.48	4.05
B4	1728.70	2262	8,143.2	8,009.65	4.63
B5	6482.64	11412	32,094.4	31,568.05	4.87
B6	6050.49	12302	34,028.7	33,470.63	5.53

The calculations show that about 4.82 mg COD may be removed by 1 cm^3 of the soil in the waste disposal field near Buhl. The longevity, however, is questionable.

Nutrient Removals

Phosphate was removed completely by the soil. The amounts of total phosphate amounts removed from the wastewater by the soil in each column are as follows.

Column Number	Phosphate Removed (mg)	Phosphate Removed (mg/cm^3 Soil)
B1	33.30	.0193
B2	132.15	.0306
B3	52.59	.03042
B4	60.169	.0348
B5	124.49	.0192
B6	128.05	.0212

About .026 mg phosphate was removed by 1 cm^3 of soil, and 95.6% of the potassium was retained in the soil. The amounts of K^+ removed from the waste are as follows.

Column Number	Potassium Removed (mg)	Potassium Removed (mg/cm^3 Soil)
B1	82.93	.048
B2	725.16	.168
B3	130.95	.076
B4	149.83	.087
B5	749.39	.116
B6	807.18	.133

Nitrogen's three forms, nitrate, ammonia, and organic, were determined in each sample. The nitrogen balance is helpful in understanding this element's movement through the soil. The balance was constructed according to the following equation.

$$NO_3 - N_{in} + NH_3 - N_{in} + \text{Org. } N_{in} = NO_3 - N_{out} + NH_3 - N_{out}$$

$$+ \text{Org. } N_{out} + \text{N converted to bacteria cells} + \text{N accumulated}$$

$$\text{in soil} + \text{N escaped to the atmosphere.}$$

Because only the NO_3^-, NH_3, and organic N were determined, the right side of the equation should exceed the left side. According to the results obtained from this study, the balance for each column was:

B1	5.696 = 164 mg
B2	49.26 = 240 mg
B3	8.99 = 192 mg
B4	10.29 = 36 mg
B5	50.52 = 216 mg
B6	51.52 = 336 mg

In this case, the right side is much more than the left side of the equation because of the great amount of NO_3^- leached from the soil. This result is consistent with the fact that the field from which the soil columns were obtained has been used for disposal previously.

Clogging of Columns

Clogging and concomitant flooding of the surface occurred in all except one of the columns during the feeding operation. In the one exception, clogging occurred at the end of the experiment. In other words, in the one-foot soil depths, the clogging reduced infiltration after 2,976 mg COD loading, in 2.5 feet after 25,638 mg COD loading, in 3.5 feet after 34,028 mg COD loading, and in 3.75 feet after 24,608 mg COD loading. The organic matter is the most important factor with respect to clogging. Many investigators have recommended that periodic loading be used to give the organic matter the chance to be degraded in an aerobic environment by the soil microorganisms. It suffices here to say that if continued application is practiced, even at a rate as low as .1 ml/min., clogging and decreased infiltration rates will result.

Quality Change in Soil

As was expected, there was an increase in the cation exchange capacity and in phosphate in the treated soil. A considerable decrease in nitrates was observed which is concomitant with the leaching by the wastewater. The presence of removable nitrate in the soil columns explains the fact that nitrates are not building up in the ground water surrounding the field, as discussed in Chapter III. The company applies its wastewater at a rate which is low enough to prevent saturation so that odor problems do not develop. The evapotranspiration of the water undoubtedly leaves nitrate in the soil. There was not a considerable increase in the OM and the K^+ because both are subject to degradation and change to another form in the soil.

Summary and Conclusions

The wastewater (effluent from a corn processing plant near Buhl, Idaho) was applied to Shelby tube type soil columns collected from a field near Buhl which had been irrigated with the same wastewater during previous years. Percolate samples were collected from the bottom of each column, and the following changes were observed after the analyses of these percolate samples: The percolate water has no color, no odor, nor unpleasant taste. The pH was raised from acidic (3.5) to neutral. The COD was removed by 98%, the $PO_4^{\equiv}$ by 100%, the K^+ by 95%, and the organic nitrogen by 50%. There was a considerable increase in the NO_3^- in solution. Concomitant changes were observed in the soil properties. Chapter III discussed the removal of BOD and fecal coliform.

The necessity of re-use of wastewater results from the steadily increasing demand of water for public supply and for industrial purposes and, on the other hand, from the limited supply of water from natural resources especially in semi-arid countries.

On the basis of this and other studies, the advantages of using the soil system in re-use and reclamation of wastewater can be stated as:

1. The treatment by percolation through the soil is generally efficient and relatively inexpensive.
2. In areas of water deficiency, reclaiming of wastewaters by soil can be much more economical than importing water from an alternative source, or than reclaiming water directly from wastewater by using advanced waste treatment methods.
3. The treatment by soil systems provides an additional opportunity for removal of bacteria and viruses and destructive chemicals (such as modern pesticides) which otherwise may be resistant to many artificial or high-rate natural treatment methods.

4. Terrestrial disposal may recharge ground water.
5. Terrestrial disposal of wastewater may not meet with public opposition as has direct re-use, even after advanced treatment to a high quality.

On the whole, the use of soil systems for reclamation of wastewater is probably the most ideal with respect to economy and other factors. As Chapters III and IV of this report has shown, renovation can be accomplished if proper and careful management is practiced.

TABLE IV-1

Wastewater Analyses (ppm)

Sample	pH	COD	NO_3^-	Organic N_2	$PO_4^{=}$	Ca^{++}	Mg^{++}	Na^+	K^+
w_1	3.45	4562	0.88	4.87	44	43	27.5	95	91
w_2	4.25	1300	0.43	5.30	11.2	27.1	36.0	100	33
w_3	5.80	1750	0.05	2.30	21.6	29	42	625	63
w_4	4.20	3600	0.25	4.30	26.6	25	30	115	69

Table IV-2. Effluent analysis, Column B1

Wastewater volume (ml)	Sample No.	Date	pH	COD (ppm)	NO_3^-N (ppm)	Organic N (ppm)	Na^+ (ppm)	K^+ (ppm)	Ca^{++} (ppm)	Mg^{++} (ppm)
147	1	9-18-71	7.80	1200	1.00	0.7	137	2.6	47	65
291	2	9-20-71	7.25	400	1.56	0.7	135	2.3	66	67
291	3	9-21-71	7.95	118	1.48	0.7	130	2.0	25	55
291	4	9-22-71	7.90	80	2.60	1.4	127	1.9	30	50
405	5	9-24-71	7.48	80	3.70	1.4	125	1.9	46	47
501	6	9-26-71	7.95	39	5.60	1.4	107	1.8	34	42
654	7	9-28-71	7.80	60	14.80	2.3	112	1.8	36	45
800	8	9-30-71	8.10	60	10.50	1.4	102	1.8	13	40
887	9	10- 1-71	7.80	80	23.00	2.3	102	1.8	30	45
964	10	10- 3-71	7.75	61	28.20	2.3	102	1.7	28	45
1048	11	10- 5-71	7.65	61	2.90	1.4	105	1.7	16	52
1051	12	10- 7-71	7.88	61	1.20	1.9	102	1.7	13	52
1084	13	10- 8-71	8.50	40	.90	1.5	110	1.8	4.4	55
1102	14	10-10-71	8.60	00	.25	1.9	112	.5	3.9	55
1252	15	10-12-71	7.90	160	0.00	2.3	132	1.6	4.0	62

NOTE: NH_3 and $PO_4^{\equiv}$ were less than 1 ppm in all samples. The flow rate was .1 ml/minute.
Start feeding on 9-16-71 at 11:30 a.m. Sample used to be collected at 12:00 a.m.

Table IV-3. Effluent analyses, Column B2

Wastewater volume (ml)	Sample No.	Date	pH	COD (ppm)	NO_3^-N (ppm)	Organic N (ppm)	Na^+ (ppm)	K^+ (ppm)	Ca^{++} (ppm)	Mg^{++} (ppm)
360	1	7-4-71	8.15	150	22	1.4	97	6.9	77	47
648	2	7-6-71	8.40	143	23	0.7	102	42	80	45
792	3	7-7-71	8.28	105	26	0.7	110	4.0	84	50
1080	4	7-9-71	7.80	89	200	0.9	190	4.2	156	115
1368	5	7-11-71	8.05	642	115	0.7	160	115	104	90
1656	6	7-13-71	8.28	292	110	1.4	145	4.4	124	102
1800	7	7-14-71	8.08	195	190	1.4	170	3.3	179	115
1944	8	7-15-71	7.50	332	245	1.4	187	3.3	207	130
2088	9	7-16-71	7.68	194	180	0.7	195	3.4	173	132
2376	10	7-18-71	7.40	234	80	0.7	180	3.1	131	120
2664	11	7-20-71	7.72	80	10	1.4	170	2.2	24	90
3096	12	7-23-71	7.48	96	2.5	0.7	155	2.0	8	75
3384	13	7-25-71	7.42	64	1.0	0.7	142	1.7	19	67
3528	14	7-26-71	8.00	16	0.0	1.4	140	1.4	6	65
3672	15	7-27-71	7.90	80	0.0	0.7	130	2.2	17.5	67
3960	16	7-29-71	7.92	16	0.0	1.9	130	1.7	16.2	62
4248	17	7-31-71	8.50	16	0.0	1.9	125	1.7	9.2	50
4680	18	8- 3-71	7.60	384	0.1	4.2	145	2.0	5.5	65
4968	19	8- 5-71	7.85	515	0.2	3.0	175	2.5	36.2	90
5326	20	8- 8-71	8.25	610	0.1	2.7	180	1.7	21.9	95
5614	22	8- 9-71	7.70	685	0.07	0.75	185	1.6	12.6	95
5902	23	8-10-71	8.10	152	0.05	1.50	155	1.4	20.7	67
6190	24	8-11-71	7.90	152	0.10	3.00	150	1.4	7.3	65
6476	25	8-12-71	8.50	76	0.15	2.26	150	1.5	8.6	67
6766	26	8-13-71	7.60	36.4	0.05	2.60	160	1.5	4.8	57
7054	27	8-15-71	8.40	00	0.10	2.26	175	1.3	5.1	62

Table IV-3. Continued

Wastewater volume (ml)	Sample No.	Date	pH	COD (ppm)	NO_3^-N (ppm)	Organic N (ppm)	Na^+ (ppm)	K^+ (ppm)	Ca^{++} (ppm)	Mg^{++} (ppm)
7198	29	8-16-71	8.75	00	0.0	2.26	157	1.0	2.6	60
7318	30	8-17-71	8.20	00	0.0	2.30	160	10.3	4.2	62
7606	31	8-18-71	7.68	7.3	0.0	2.30	140	0.9	14.7	65
7894	32	8-19-71	7.98	18.2	0.0	1.50	167	1.0	8.5	67
8182	33	8-20-71	8.02	36.4	0.0	2.30	145	1.0	8.0	80
8470	34	8-21-71	7.85	327.6	0.0	2.30	177	1.2	60	140
8758	35	8-22-71	7.70	1330	0.3	1.50	187	1.3	154	177
9046	36	8-23-71	7.35	2220	0.2	1.50	305	1.6	289	205
9334	37	8-24-71	7.20	2520	0.1	2.30	337	1.6	321	222
9622	38	8-25-71	7.02	2440	0.4	2.60	377	1.7	270	212
9910	39	8-26-71	7.20	2725	0.4	2.60	427	2.0	231	202
10198	40	8-27-71	7.00	1680	0.3	2.30	450	1.9	337	185
10486	41	8-28-71	7.02	1715	0.1	3.00	475	1.9	328	182
10774	42	8-29-71	6.90	1680	0.2	2.30	250	1.8	315	190

NOTE: NH_3 and $PO_4^{\equiv}$ values were less than 1 ppm in all samples. Feeding started on 7-1-71 at 12:00 a.m. Flow rate was 0.05 ml/min for the first 24 hours, then increased to 0.1 ml/min and thento 0.2 ml/min on 8-7-71.

Table IV-4. Effluent analyses, Column B3

Wastewater volume (ml)	Sample No.	Date	pH	COD (ppm)	NO_3^-N (ppm)	Organic N (ppm)	Na^+ (ppm)	K^+ (ppm)	Ca^{++} (ppm)	Mg^{++} (ppm)
147	1	9-18-71	7.65	1400	290	0.7	235	1.6	300	205
291	2	9-19-71	7.60	300	215	0.7	202	1.5	264	162
435	3	9-20-71	7.75	158	98	1.4	152	1.2	111	110
723	4	9-22-71	7.60	80	11	1.4	127	1.0	54	75
867	5	9-23-71	7.70	00	0.0	2.3	125	0.9	26	62
915	6	9-25-71	7.75	20	0.25	1.4	132	1.0	17	65
1131	7	9-27-71	7.50	00	0.0	2.3	135	0.9	26	62
1293	8	9-29-71	8.00	00	0.0	1.9	140	1.0	86	57
1371	9	9-30-71	7.90	21	0.2	2.3	130	0.9	66	55
1392	10	10- 1-71	7.88	61	0.1	2.3	142	0.8	8.8	62
1530	11	10- 3-71	8.35	00	0.0	1.5	152	0.9	2.4	67
1614	12	10- 5-71	7.97	40	0.0	1.9	152	0.6	2.8	100
1710	13	10- 6-71	7.80	260	0.0	1.5	165	0.7	8.5	130
1902	14	10- 8-71	8.28	580	0.0	1.5	152	0.8	17.0	142
1977	15	10- 9-71	7.88	740	0.0	1.9	130	0.7	41.4	150

NOTE: NH_3 and $PO_4^{\equiv}$ were less than 1 ppm in all samples. Start feeding on 9-16-71 at 11:30 a.m. Flow rate,0.1 ml/min.

Table IV-5. Effluent analyses, Column B4

Wastewater volume (ml)	Sample No.	Date	pH	COD (ppm)	NO_3^-N (ppm)	Organic N (ppm)	Na^+ (ppm)	K^+ (ppm)	Ca^{++} (ppm)	Mg^{++} (ppm)
147	1	9-18-71	7.40	1600	274	0.7	317	1.4	323	255
291	2	9-19-71	7.65	200	215	2.3	265	1.0	206	190
435	3	9-20-71	7.80	60	68	2.3	190	0.8	72	100
723	4	9-22-71	8.00	00	6.4	1.9	152	0.7	34	60
1011	5	9-24-71	8.15	00	1.2	1.9	140	0.5	9.5	47
1299	6	9-26-71	8.05	00	.64	2.3	127	0.5	13	42
1449	7	9-28-71	7.85	39	.64	1.4	125	<0.5	33	42
1529	8	9-30-71	8.08	39	.64	1.4	112	<0.5	24	35
1673	9	10- 1-71	8.05	20	.64	1.4	100	<0.5	5.1	30
1811	10	10- 3-71	8.10	21	0.0	1.0	102	<0.5	14	35
1931	11	10- 4-71	8.15	469	0.0	0.7	112	<0.5	6.9	40
2118	12	10- 6-71	7.80	1162	0.0	1.0	127	<0.5	33	67
2262	13	10- 7-71	7.60	1407	0.0	1.4	152	<0.5	54	125

NOTE: NH_3 and $PO_4^{\equiv}$ were less than 1 ppm in all samples. Start feeding on 9-16-71 at 11:30 a.m. Flow rate, 1 ml/min.

Table IV-6. Effluent analyses, Column B5

Wastewater volume (ml)	Sample No.	Date	pH	COD (ppm)	NO_3^-N (ppm)	Organic N (ppm)	Na^+ (ppm)	K^+ (ppm)	Ca^{++} (ppm)	Mg^{++} (ppm)
1030	1	7-10-71	8.15	143	3.5	0.7	60	8.0	38	47.5
1224	2	7-11-71	8.42	117	8.3	0.4	50	4.2	38	45.0
1512	3	7-13-71	8.42	244	3.1	1.4	50	4.2	39	47.5
1656	4	7-14-71	8.45	195	10.0	1.4	50	3.7	41	47.5
1800	5	7-15-71	8.35	156	35.0	0.7	57.5	4.5	54	57.5
1944	6	7-16-71	8.08	117	85.0	0.7	77.0	5.2	82	75
2088	7	7-17-71	8.45	75	120.0	0.4	92	5.8	118	95
2232	8	7-18-71	8.25	80	175.0	0.4	107	6.4	152	110
2520	9	7-20-71	8.38	144	160.0	0.4	130	6.9	123	112
2952	10	7-23-71	8.08	64	160.0	0.7	132	6.6	68	110
3240	11	7-25-71	7.88	48	77.5	2.3	125	6.0	34	100
3384	12	7-26-71	7.60	32	65.0	2.6	120	6.0	61	97.5
3528	13	7-27-71	8.40	16	17.0	2.6	130	10.0	7.3	105
3816	14	7-29-71	7.80	96	1.0	2.9	132	12.0	17	100
4104	15	7-31-71	7.54	57	5.0	1.1	145	5.6	16.1	100
4536	16	8- 4-71	7.90	95	0.05	2.6	137	5.5	37.3	85
4680	17	8- 5-71	8.10	152	5.6	3.8	142	3.6	20.0	85
4968	18	8- 8-71	8.62	114	0.23	4.1	82	5.8	4.1	55
5256	19	8- 9-71	8.63	131	0.05	1.5	132	5.9	3.0	80
5544	20	8-10-71	8.69	152	0.0	2.3	130	5.8	2.9	90
5832	21	8-11-71	8.68	76	0.05	1.9	130	5.7	3.2	92
6120	22	8-12-71	8.40	152	0.15	2.3	125	5.9	4.9	100
6408	23	8-13-71	8.60	36	0.0	1.9	125	5.6	6.6	100
6696	24	8-14-71	8.18	71	0.0	1.5	127	5.5	3.9	110
6984	25	8-15-71	8.48	107	0.0	2.3	140	5.6	3.5	110
7128	26	8-16-71	7.92	146	0.08	1.5	137	4.8	6.8	105
7416	28	8-17-71	8.40	143	0.0	2.3	167	9.3	4.1	110
7560	29	8-18-71	8.22	36	0.0	2.3	140	4.9	4.5	102

Table IV-6. Continued

Wastewater volume (ml)	Sample No.	Date	pH	COD (ppm)	NO_3^-H (ppm)	Organic N (ppm)	Na^+ (ppm)	K^+ (ppm)	Ca^{++} (ppm)	Mg^{++} (ppm)
7848	30	8-19-71	7.68	71	0.05	2.6	150	5.0	12.6	110
8136	31	8-21-71	8.12	143	0.00	2.6	190	6.7	5.4	100
8424	32	8-22-71	8.38	143	0.00	2.3	172	5.0	5.4	125
8712	33	8-23-71	7.80	2168	0.00	3.0	437	32.0	26.0	217
8964	34	8-24-71	7.55	2060	0.05	3.0	180	4.5	241	110
9252	35	8-25-71	7.95	343	0.12	2.6	197	5.7	13.9	110
9396	36	8-26-71	7.63	610	0.12	2.3	225	5.9	44	140
9684	37	8-27-71	7.30	820	0.15	2.6	225	6.4	174	192
9972	38	8-28-71	7.10	1600	0.00	4.1	250	5.2	355	242
10260	39	8-29-71	7.25	1220	0.08	3.0	225	7.8	313	325
10548	40	8-30-71	7.53	1412	0.25	1.5	225	6.8	207	277
10836	41	8-31-71	7.45	1313	0.35	2.3	200	5.8	247	295
11124	42	9- 1-71	7.10	1470	0.35	1.5	175	6.2	373	325
11412	43	9- 2-71	7.15	1412	0.40	2.3	175	6.8	387	337

NOTE: NH_3 and $PO_4^{\equiv}$ values were less than 1 ppm in all samples. Feeding started on 7-21-71 at 12:00 a.m. Flow rate was 0.05 ml/min for the first 24 hours, then increased to 1 ml/min and lastly to 0.2 ml/min on 8-7-71.

Table IV-7. Effluent analyses, Column B6

Wastewater volume (ml)	Sample No.	Date	pH	COD (ppm)	NO_3^-N (ppm)	Organic N (ppm)	Na^+ (ppm)	K^+ (ppm)	Ca^{++} (ppm)	Mg^{++} (ppm)
1080	1	7-10-71	8.38	107	1.4	0.7	33.4	2.2	17	15.7
1224	2	7-11-71	8.45	51	2.2	0.7	33.2	1.9	19	16.5
1512	3	7-13-71	8.50	146	3.2	1.4	36.8	2.0	21	17.7
1656	4	7-14-71	8.40	97.5	8.3	1.4	40.8	2.1	23	19.0
1800	5	7-15-71	8.35	48.8	25.0	0.7	45.9	2.2	29	22.4
1944	6	7-16-71	8.20	78	39.0	1.4	53.2	2.5	36	28.1
2232	7	7-18-71	7.65	58	110.0	1.4	70	3.4	68	45.0
2520	8	7-20-71	7.60	40	185.0	0.7	95	3.9	88	72.5
2952	9	7-23-71	7.95	96	242.5	0.7	107	4.4	116	42.5
3240	10	7-25-71	7.78	64	173.0	0.0	112	3.8	152	100
3384	11	7-26-71	7.40	32	153	0.75	107	3.5	145	92.5
3528	12	7-27-71	7.30	00	127	0.75	112	3.7	103	80
3816	13	7-29-71	7.65	00	75	0.75	107	5.7	48.4	67
4104	14	7-31-71	7.30	00	35	3.0	100	4.8	46.0	62
4814	15	8- 5-71	7.75	76	00.4	1.5	90	3.6	17.2	95
5115	16	8- 8-71	8.30	305	16.0	1.5	82	3.3	32.1	60
5390	18	8- 9-71	8.40	00	1.7	1.5	82	3.1	7.0	50
5966	19	8-11-71	8.40	95	1.6	2.3	62	3.0	6.6	50
6254	20	8-12-71	8.40	57	2.1	2.3	60	3.2	4.8	55
6542	21	8-13-71	8.38	00	2.32	1.5	60	3.0	4.6	47
6830	22	8-14-71	7.60	36	1.90	0.75	60	3.1	43	55
7118	23	8-15-71	8.30	18	3.70	2.30	65	3.0	5.9	55
7262	25	8-16-71	8.04	72	0.45	1.5	70	5.2	7.4	60
7550	26	8-17-71	7.70	54	0.12	1.5	65	2.8	45	62
7838	27	8-18-71	7.60	54	0.15	2.3	67	2.7	18	62
8126	28	8-19-71	7.55	36	0.08	2.3	70	2.7	22	62
8414	29	8-20-71	7.90	18	0.05	1.5	75	3.1	9.0	67

Table IV-7. Continued

Wastewater volume (ml)	Sample No.	Date	pH	COD (ppm)	NO_3^-N (ppm)	Organic N (ppm)	Na^+ (ppm)	K^+ (ppm)	Ca^{++} (ppm)	Mg^{++} (ppm)
8702	31	8-21-71	8.40	54	0.0	1.5	85	3.2	5.3	65
8990	33	8-22-71	7.99	37	0.05	2.3	65	2.5	66	57
9278	35	8-23-71	7.10	332	0.35	1.5	95	2.9	136	95
9566	36	8-24-71	7.65	1099	0.12	1.5	200	4.4	269	207
9854	38	8-25-71	7.20	2100	0.0	1.9	225	6.1	315	235
10142	39	8-26-71	7.18	1487	0.45	1.5	250	5.3	374	360
10430	40	8-27-71	7.40	2060	0.12	2.3	250	5.1	374	240
10718	41	8-28-71	7.28	952	0.08	1.5	250	6.8	144	245
11006	42	8-29-71	7.30	1752	0.05	1.5	250	4.9	390	247
11294	43	8-30-71	7.70	1730	0.35	1.5	275	5.0	276	240
11582	44	8-31-71	6.95	1688	0.12	1.5	300	4.8	251	245
11726	45	9- 1-71	7.20	1730	0.08	1.5	300	5.4	363	255
12014	46	9- 2-71	7.50	1842	0.08	1.5	325	5.5	307	250
12302	47	9- 3-71	7.43	1805	0.12	1.5	400	5.2	328	242

NOTE: NH_3 and $PO_4^{\equiv}$ values were less than 1 ppm in all samples. Start feeding on 7-2-71 at 12:00 a.m. Flow rate was 0.05 ml/min for the first 24 hours and then increased to 0.1 ml/min. On 8-7-71, the flow rate was increased to 0.2 ml/min.

Table IV-8. Nontreated soil analysis

Column	CEC in meq/100 g	*Extractable Metallic Cations				NO_3^-N (ppm)	$PO_4^{\equiv}$ (ppm)	O. M. (%)	pH (units)
		Ca^{++}	Mg^{++}	Na^+	K^+				
B1 s	6.1	17.2	5.1	.85	.55	30.50	8.4	1.4	8.20
B1 b	4.7	16.1	5.2	.66	.22	8.75	1.0	1.5	8.60
B2 s	6.0	17.1	5.4	.55	.57	14.50	17.2	1.8	3.15
B2 b	5.0	16.8	7.7	.71	.47	2.50	12.5	1.6	8.45
B3 s	6.2	14.2	5.9	.78	.56	18.25	8.7	1.8	8.30
B3 b	6.9	16.0	5.2	.55	.19	17.00	2.8	0.7	8.50
B4 s	6.2	13.2	6.2	.96	.55	18.25	19.2	0.8	8.25
B4 b	8.6	16.5	7.8	.82	.13	14.75	4.5	0.9	8.35
B5 s	6.1	16.0	5.7	.44	.13	9.75	14.3	0.8	8.10
B5 b	5.2	16.4	7.4	.78	.63	9.00	10.2	2.3	8.40
B6 s	5.4	16.7	11.2	.74	.62	37.75	16.5	0.7	8.30
B6 b	6.5	17.0	5.4	.45	.47	33.75	8.4	1.6	8.60

NOTE: s = sample taken from surface of column; b = sample taken from bottom of column.

* meq/100 g

Table IV-9. Treated soil analysis

Column	CEC in meq/100g	*Extractable Metallic Cations				NO_3^-N (ppm)	$PO_4^{\equiv}$ (ppm)	O. M. (%)	pH (units)
		Ca^{++}	Mg^{++}	Na^+	K^+				
B1 s	9.3	17.4	4.4	.62	.74	13.25	30.2	1.3	8.35
B1 b	9.0	16.8	4.5	.67	.22	5.25	5.0	1.7	8.70
B2 s	9.8	17.8	3.9	2.07	1.03	31.00	24.0	1.6	8.20
B2 b	8.3	16.5	7.2	2.00	.23	4.75	4.5	1.8	8.50
B3 s	10.5	12.9	5.4	.61	.69	16.25	13.5	1.2	8.30
B3 b	7.8	16.8	4.5	.38	.23	5.75	5.5	1.8	8.58
B4 s	10.0	11.6	5.0	.61	.62	28.25	15.2	.6	8.30
B4 b	9.0	17.0	4.8	.44	.14	6.50	4.3	.9	8.45
B5 s	9.7	10.6	3.9	5.74	1.79	41.00	22.2	1.5	8.26
B5 b	7.5	15.8	7.7	.76	.37	4.00	3.7	1.3	8.48
B6 s	9.7	17.4	4.2	1.56	.93	36.05	18.8	1.2	8.30
B6 b	8.0	15.7	6.8	2.13	.48	3.50	4.0	.2	8.45

NOTE: s = sample taken from surface of column ; b = sample taken from bottom of column.

*meq/100 g

CHAPTER V

MATHEMATICAL MODEL OF THE CAMAS BASIN GROUND-WATER FLOW SYSTEM

Introduction

In many cases it is necessary to understand the natural ground-water flow system prior to the implementation of an artificial recharge program. Mathematical modeling is one of the techniques which can be utilized to interpret the natural hydrologic environment. This chapter deals with the application of such a model to the Camas basin in Idaho.

Finite-Element Background

The finite-element technique is a numerical method of analysis in which the region of interest is divided into discrete elements. The method was originally used in stress analysis, particularly in the field of structural engineering. A discrete solution provides values only at discrete points within the problem region rather than the continuous values obtained by analytical solutions. Discrete solutions are adequate in many cases and permit treatment of complex boundary conditions; the discrete method also provides approximate solutions to problems which cannot be handled by analytical means. Details of the theory of the method are presented by Zienkiewicz (1965, 1966, 1967).

The first application of finite-element technique to seepage problems was made by Zienkiewicz (1966). His work provided the theory on which subsequent seepage studies and computer programs were based. The accuracy of the finite-element technique has compared favorably with anaytical methods in a number of water flow problems (Tomlin, 1966; Zienkiewicz, 1966, 1967).

In 1967, Finn (1967) at the University of Vancouver and Taylor and Brown (1967) of the University of California at Berkeley used a matrix and finite-element methods to locate the phreatic surface in a dam. Taylor later developed a technique for finding the phreatic surface without the trial-and-error location of the exit point, which was required with Finn's method. Kealy (1970) and Kealy and Williams (1971) describe application of the finite-element technique to a study of seepage patterns in mill-tailings dams.

The present study adapts the program developed by Taylor and used by Kealy to modeling an entire ground-water basin in southern Idaho. As far as we know, it is the first use of the finite-element method to a basin-wide problem. The study is discussed in greater detail by Wallace (1973).

Isolation of the Study Region

The first step in applying any numerical technique is to define the region of study in terms of its boundary conditions. The effects of these conditions on flow and the relationship of the various elements can then be determined. Boundaries are specified by the geometry of the problem and may include one or more impermeable boundaries, a hydrostatic upstream equipotential line, a free-water surface (if this program option is used) and a downstream equipotential line.

The flow region is divided by the program into elements consisting of plane triangles with nodes at each vertex. The finite-element mesh may be constructed of quadrilateral elements for convenience in forming it initially since the program automatically divides the quadrilaterals into triangular elements (see Figure 1).

The elements should be numbered sequentially beginning at the lower left and numbering upward in each column of elements. The nodes must be numbered sequentially upward in each column, beginning at the left edge of the mesh. No element can have more than four nodes; a change of mesh size requires construction of triangular elements in the transition column.

Darcy's Law in Terms of Pressure and Gravitational Potential

The following derivations are from Kealy and Busch (1971).

The theory of waterflow through porous media is based on the classical experiment originally performed by Darcy in 1856. Mathematical models may be validly used only if Darcy's assumptions hold true (1, p. 174).

Darcy's law is expressed as follows (1, p. 158, 162):

$$q = -ki, \tag{1}$$

where q = unit flow (L/T),

k = coefficient of permeability (L/T),

$i = dh/dl = h/L$ = hydraulic gradient (dimensionless),

L = length (L),

T = time (T),

and h = hydraulic head (L).

In order to use the finite-element technique, Darcy's law must be expressed in this form:

$$q = -K(\partial P/\partial x + \rho g), \tag{2}$$

where K = coefficient of permeability/ρg (TL^3/M) = computer coefficient of permeability,

P = pressure (M/LT^2),

ρ = fluid density (M/L^3),

and g = gravity (L/T^2).

This expression can be derived in the manner shown in equations 3 through 16. The additional notation used consists of the following:

θ = fluid potential (L^2/T^2).

Z = elevation above a standard datum (L).

P = pressure at a point in the porous medium where θ is desired (M/LT^2).

P_o = pressure at the standard datum (M/LT^2).

k = saturated hydraulic conductivity (coefficient of permeability) (L/T).

q_y = rate of flow in y direction (L/T).

Using Hubbert's approach (4),

$$h = \theta/g = Z + 1\rho g \int_{P_o}^{P} dp, \tag{3}$$

provided ρ and g are considered constant. Now, consider for example the potential gradient in the vertical direction (y direction):

$$\partial h/\partial y = \partial Z/\partial y + 1/\rho g(\partial p/\partial y); \tag{4}$$

therefore, $$\partial h/\partial y = 1 + (1/\rho g)\ (\partial p/\partial y), \tag{5}$$

or $$\rho g(\partial h/\partial y) = \rho g + \partial p/\partial y. \tag{6}$$

Consequently, $$\partial h/\partial y = (\rho g + \partial p/\partial y)/\rho g. \tag{7}$$

According to Darcy's law,

$$q_y = -k(\partial h/\partial y), \tag{8}$$

where k = saturated hydraulic conductivity. By substitution,

$$q_y = -k\ \frac{\rho g + \partial p/\partial y}{\rho g}, \tag{9}$$

or $$q_y = -k/\rho g\ (\rho g + \partial p/\partial y. \tag{10}$$

Now let $-K = -k/\rho g$; then,

$$q_y = -K_y\ (\rho g + \partial p/\partial y). \tag{11}$$

By similar reasoning, $q_x = -K_x\ (\partial p/\partial x + 0)$ ($g = 0$ in x direction), where K is the method of expressing permeability in a manner concenient for use in the computer.

It is known that pressure

$$p = \rho gh; \tag{12}$$

therefore, by substitution,

$$q_y = -K\left(\rho g + \rho g\,\frac{\partial h}{\partial y}\right). \tag{13}$$

Thus, $$q_y = -\rho gK\left(1 + \frac{\partial h}{\partial y}\right), \tag{14}$$

or in terms of actual coefficient of permeability, k,

$$q_y = -\rho gk/\rho g\left(\frac{\partial h}{\partial y} + 1\right) = -k\left(\frac{\partial h}{\partial y} + 1\right). \tag{15}$$

Consequently, if all nodal pressures are expressed in terms of hydrostatic head and if $\rho g = 1$, then K (computer) can be replaced by k (measured). This practice was followed throughout the investigation. If program input pressures are in feet of water and if nodal coordinates are in feet, then q will have the same units as the input k units. Equation 2 can be expressed in matrix form as

$$\{q\} = -\{k\}\{\partial P/\ x + \rho g\ , \qquad (16)$$

where {q} is a matrix of the flow velocities, {k} is a matrix of the coefficients of permeability, P is the fluid pressure at a point {x}, and ρg is the gravitational term.

Directional Relationships: Theory and Application

Because of testing limitations, k is measured parallel with and perpendicular to soil layering. Two sets of coordinates are required, designated x y and x'y'. Directional permeabilities are specified in the x'y' coordinate system as K_x' and K_y'. The stratification angle is specified in the coordinate system x y.

$$\begin{Bmatrix} q_x' \\ q_y' \end{Bmatrix} = - \begin{vmatrix} K_x' & 0 \\ 0 & K_y' \end{vmatrix} \begin{vmatrix} \partial P/\partial x' + 0 \\ \partial P/\partial y' + \rho g \end{vmatrix} . \qquad (17)$$

Note that K must be measured in the field in x'y' system.

Using standard transformation techniques (12), it can be shown that

$$\begin{Bmatrix} q_x \\ q_y \end{Bmatrix} = \begin{vmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{vmatrix} \begin{vmatrix} q_x' \\ q_y' \end{vmatrix} \qquad (18)$$

and

$$\begin{Bmatrix} \partial P/\partial x' + \rho g \\ \partial P/\partial y' + \rho g \end{Bmatrix} = \begin{vmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{vmatrix} \begin{Bmatrix} \partial P/\partial x + \rho g_x \\ \partial P/\partial y + \rho g_y \end{Bmatrix} . \qquad (19)$$

Combine all of the above transformations to rewrite Darcy's law in terms of global coordinates x, y:

$$\begin{Bmatrix} q_x \\ q_y \end{Bmatrix} = - \begin{vmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{vmatrix} \begin{vmatrix} K_x' & 0 \\ 0 & K_y' \end{vmatrix} \begin{vmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{vmatrix} \begin{Bmatrix} \partial P/\partial x + \rho g_x \\ \partial P/\partial y + \rho g_y \end{Bmatrix} . \qquad (20)$$

Note that the permeability matrix in x,y is

$$\begin{vmatrix} K_{xx} & K_{xy} \\ K_{yx} & K_{yy} \end{vmatrix} = \begin{vmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{vmatrix} \begin{vmatrix} K_x' & 0 \\ 0 & K_y' \end{vmatrix} \begin{vmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{vmatrix} . \qquad (21)$$

Therefore, the working equation in matrix form becomes

$$\begin{Bmatrix} q_x \\ q_y \end{Bmatrix} = - \begin{vmatrix} K_{xx} & K_{xy} \\ K_{yx} & K_{yy} \end{vmatrix} \begin{Bmatrix} \partial P/\partial x + \rho g_x \\ \partial P/\partial y + \rho g_y \end{Bmatrix} . \qquad (22)$$

Linear Pressure Variations: Basic Assumptions

With Darcy's law in the form of equation 22 and with the assumptions necessary for its use (1), it can be employed in flow analysis. However, an additional assumption is necessary: In each finite element (triangle) in the model, the pressure varies linearly with the distance from nodes. Therefore, from equation 2, it can be seen that the fluid (water) velocities will be constant in time since the permeability and the gravity term ρg are constant for any element.

Since the boundary node pressures are known in any problem under solution, it becomes advantageous to work in terms of node values. In any triangular element, the linear pressure variation can be expressed in terms of the pressures as the vertices i, j, and k of the triangle; these are called nodal pressures.

Derivation of Linear Pressure Distribution in Terms of Nodal Pressure

The following derivation is after Taylor. For a general linear spatial variation of pressure in a plane, the following applies:

$$P = A_1 + A_2X + A_3Y. \qquad (23)$$

The constants A_1, A_2, and A_3 can be expressed in terms of the nodal pressures located at the vertices i, j, and k, respectively, of a plane triangle by evaluating equation 23 at each node. Accordingly,

$$\begin{Bmatrix} P_i \\ P_j \\ P_k \end{Bmatrix} = \begin{vmatrix} 1 & X_i & Y_i \\ 1 & X_j & Y_j \\ 1 & X_k & Y_k \end{vmatrix} \begin{Bmatrix} A_1 \\ A_2 \\ A_3 \end{Bmatrix}. \tag{24}$$

Equation 24 may be solved for the value of A . Thus,

$$\begin{Bmatrix} A_1 \\ A_2 \\ A_3 \end{Bmatrix} = 1/\Delta \begin{vmatrix} D_{jk} & D_{ik} & D_{ij} \\ (Y_j - Y_k) & (Y_k - Y_i) & (Y_i - Y_j) \\ (X_k - X_j) & (X_i - X_k) & (X_j - X_i) \end{vmatrix} \begin{Bmatrix} P_i \\ P_j \\ P_k \end{Bmatrix}, \tag{25}$$

where $\Delta = D_{jk} + D_{ik} + D_{ij}$,

and $D_{jk} = X_j Y_k - X_k Y_j$,

$D_{ik} = X_k Y_i - X_i Y_k$,

and $D_{ij} = X_i Y_j - X_j Y_i$.

Using equations 23 and 25, then

$$P = \langle 1XY \rangle \begin{Bmatrix} A_1 \\ A_2 \\ A_3 \end{Bmatrix}. \tag{26}$$

Differentiating with respect to X and Y,

$$\begin{Bmatrix} \partial P/\partial x \\ \partial P/\partial y \end{Bmatrix} = \begin{vmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \end{vmatrix} \begin{Bmatrix} A_1 \\ A_2 \\ A_3 \end{Bmatrix}. \tag{27}$$

Thus the pressure gradients are constant in space for any element. From equation 2 is derived

$$\begin{Bmatrix} q_x \\ q_y \end{Bmatrix} = \begin{vmatrix} K_{xx} & K_{xy} \\ K_{xy} & K_{yy} \end{vmatrix} \begin{Bmatrix} \partial P/\partial x - \rho g x \\ \partial P/\partial y - \rho g_y \end{Bmatrix}. \tag{28}$$

Consequently, for constant permeabilities {K} and gravitational term {ρg}, the flow rates {q} will also be constant. Therefore, the flow problem is steady state, and the right-hand side of the continuity equation can subsequently be set equal to zero.

Continuity Equation

If no fluid is placed in or derived from storage in each element, then the continuity equation must be expressed for steady-state conditions; specifically, the flow into the region of study must equal the flow out of the region. If this concept is used on a single element of the region being studied and if a linear spatial-pressure distribution within the element is assumed, one can construct an approximate solution. Further, taking a large number of elements in the region of interest makes possible very accurate approximations.

A single element with nodal pressures, nodal volume rate of flow, element velocities, and element dimensions is portrayed in Figure V-2. The element velocities q_x and q_y, computed from the Darcy equation 2, are expressed in terms of the nodal pressures at the vertices k, j, and k, which are denoted by P_i, P_j, and P_k, respectively. Once q_x and q_y are known, equivalent nodal flows Q can be computed; that is,

$$(Q_x)_k^R = (Q_x)_j^R = 1/2\ q_x\ (P_i,\ P_j,\ P_k)b_k. \tag{29}$$

(Superscripts denote the following: R is right, L is left, T is top; and B is bottom.)

Treating the total fluid exiting at nodes $(Q_i Q_j,\ Q_k)$ as positive gives

$$Q_i = (Q_y)_i^T - (Q_y)_i^B - (Q_x)_i^L,$$

$$Q_j = (Q_y)_j^T - (Q_y)_j^B + (Q_x)_j^R - (Q_x)_j^L,$$

and

$$Q_k = (Q_y)_k^T - (Q_x)_k^L + (Q_x)_k^R. \tag{30}$$

By considering each element connected to any node M, continuity of flow at the node is insured by

$$\sum_{i=1}^{m} Q_M^i = 0, \tag{31}$$

where m is the number of elements connected to node M and i is the particular element from which Q_M^i is computed. Computing equation 31 for each node in the finite-element model requires a set of simultaneous algebraic equations in terms of the nodal pressures P_M. (Recall that q_x and q_y are expressed for each element in terms of the element's nodal pressures; consequently, each Q_M^i in equation 31 will also be in terms of the nodal pressures.) The algebraic equations were developed by considering each element in turn; the fact that certain nodal pressures are known and assigned can be disregarded. For example, the pressures may be known (or assumed) for all nodes located along the side boundaries. Before the algebraic equations are solved simultaneously, the equation for each node at which the pressure is known is modified to produce this pressure as the solution. The value of all other nodal pressures is obtained from the solution to the simultaneous equations. Once the pressure distribution is ascertained, the flow velocities in each element can be computed from Darcy's equations. Further, if pressure distribution is known, then the potentials, or hydraulic head, can easily be calculated and the flow net derived.

Determination of Location of Free Water Surface

The initial location of the free water surface may be estimated, or assumed known, when the region of study (the flow region) is defined. In most real problems, the location is <u>not</u> known. Herein lies one of the main advantages of this particular numerical solution: With only minimal known boundary conditions, one can analyze an anisotropic flow system, as well as establish the locations of the phreatic surface.

In order to locate the free water surface, the investigator must be able to select the position of the surface that has both zero flow normal to it and zero atmospheric pressure on it. Using finite-element estimation, one should specify these two conditions at only the nodal points along the free surfaces. The final node location of the free water surface is not known beforehand.

The two foregoing conditions are specified for any node on the free surface as

$P \rightarrow 0$ (where 0 is taken as atmospheric pressure)

and q (normal to free surface) $\equiv 0$.

The free water surface is finally located at those nodes where $q = 0$ and where P approaches 0.

It is not possible initially to specify correctly all three of the foregoing conditions because the node location at which the flow will be zero (and where the pressure will be atmospheric) is not known; therefore, the node location along the free surface must be assumed. Further, because of the number of unknowns and equations to be solved, one must set either $P = 0$ or $q = 0$. In this analysis q is always set equal to zero. Once so positioned, the initially located free surface nodes can be allowed to move until they reach points where $P \rightarrow 0$. This procedure provides the final location of the free surface nodes since all three conditions are satisfied ($P \rightarrow 0$, $q = 0$, and free surface nodes are specified).

Application of the Finite-Element Technique

The following facts are pertinent to the use of the finite-element model we use.

1. A sound knowledge of fluid mechanics and of soil mechanics is required so that realistic boundary conditions and input parameters can be selected.

2. A graphic description of the problem to be solved is necessary to enable a user to construct the finite-element mesh.
3. Input units and dimensions for the study region and model must be consistent. For example, in this study pressure is expressed as head (length), permeability as velocity (length/time) and flow as a velocity (length/time). If "1" is used for the density of the fluid and velocities are in centimeters/time, the computed pressures are in feet of water. Originally the program we use was designed to use only "1" as density and using density in any other units gives flows in mixed units. We have modified the program to use density in any units and, if velocity units are consistent, flow units will be consistent.
4. Output listed as "Total Flow" is the resultant flow velocity from the center of an element.
5. The program we use allows no flow across any boundary node of the area enclosed by the mesh unless pressure distribution is known and assigned. Any boundary node without a pressure is considered impermeable.
6. Zero pressure may be assigned to any boundary node known to have no pressure other than atmospheric. This should be done with care for it is possible to open a "drain" in the mesh and lose fluid. The gradient may be changed by this operation and flow may be created toward the "drain" from all directions in the mesh.
7. A pressure may be assigned either to any interior node or the program will compute it.
8. If pressures are assigned, care should be taken to see that they are realistic since the program forces the pressure distribution to conform to those supplied as input.
9. The program we use considers all material included within the mesh to be saturated, however, a free-water surface may be established in the mesh by

making use of the free-surface subroutine of the program. The use of the free-surface feature involves some limitations and restrictions on placing the free-surface nodes. This feature was not used in the present study and is not discussed. Kealy (1970) and Kealy and Busch (1970, 1971) used the program to locate the free surface and they describe the application with several examples.

10. There are features built into the program for generating nodes, boundary conditions and elements. These features can be used after some experience in mesh or grid construction has been developed. They can save considerable time in constructing models.
11. In a problem with a large number of nodes and/or elements there is a strong possibility of exceeding the available computer storage. The following formula for construction was obtained from Michael M. McDonald, research engineer at the Spokane Mining Research Laboratory, U. S. Bureau of Mines, Spokane; it enables a user to determine the number of words of storage required, which must be less than or equal to 20,000:

$$1 + 2(\text{No. of materials}) + 6(\text{No. of nodes}) + 6(\text{No. of elements}) + (\text{Maxband times No. of Nodes}) \leq 20{,}000$$

    Maxband is equal to (highest node number - lowest node number) + 1

12. A complete program listing may be obtained from the University of Idaho Computer Center and program documentation is given by Kealy (1970), by Kealy and Busch (1971), and Wallace (1973).

Camas Prairie

Location and Extent

Camas Prairie is located in the west-central part of southern Idaho. The center of the prairie is about 55 miles north of Twin Falls and about 75 miles east-southeast of Boise. The drainage area for Camas Prairie consists of about 650 square miles, nearly all of which is located in Camas County. Less than 100 square miles is located in eastern Elmore County. The relatively flat surface of the prairie proper covers about 215 square miles. The area is bounded by meridians 114° 30' - 115° 30' west and parallels 43° 10' - 43° 35' north. The location relative to the state is shown in Figure V-3.

Previous Investigations

Two reports are available on the ground-water conditions and resources of Camas Prairie. Piper (1925) did a reconnaissance study on the area and also presented an interpretation of the geologic history of the area. Walton (1962) made a study for the U. S. Bureau of Reclamation and described the geology, ground-water resources, and quality and temperature of the water. Data from both Piper's and Walton's reports and data gathered during the summers of 1970 and 1971 are used in this report.

Physiography and Drainage

Camas Prairie is located in the Northern Rocky Mountain physiographic province and is an eastward-trending intermontane trough about 40 miles in length and about 8 miles wide. The trough is partially filled with detrital material carried in from the adjacent mountains. The sediments were deposited during the time when the eastern outlet of the valley was dammed by lava flows, possibly beginning in Pliocene time and continuing into the Pleistocene and Recent.

The prairie is a gently undulating plain that slopes southeastward at about 7 feet per mile from an altitude of 5200 feet above mean sea level at the west end. Broad, low alluvial fans formed by intermittent tributary streams that drain the northern mountains slope southward at about 40 feet per mile from the foot of the mountains.

Camas Prairie is bounded on the north by the Soldier Mountains, which rise to an altitude of 10,095 feet at Smoky Dome, 7 miles north of the prairie. The Mount Bennett Hills on the south reach an altitude of about 6800 feet and separate the prairie from the Snake River Plain. Low summits on the west, with altitudes of about 6200 feet, separate the prairie from the basin of the South Fork of the Boise River.

The prairie terminates 8 miles east of Fairfield against an undulating plain of basalt and in part against Quaternary alluvium that is somewhat older than the bulk of the surface material in the prairie. The older alluvium is slightly more consolidated and does not contain pebbles of basalt (Piper, 1925, p. 9). The alluvium forms a series of low, rounded hills at the east end of the basin. The basalt plain joins the main Snake River Plain 24 miles east of Fairfield.

Camas Creek is a sluggish, meandering stream which flows eastward along the southern edge of the prairie with a gradient of about 5 feet per mile between Hill City and Blaine. East of Blaine, the creek flows in a deep canyon which it has cut into the basalt. Camas Creek drains an area of about 650 square miles and discharges into the Big Wood River which is a tributary to the Snake River.

Within the Camas Prairie basin Elk, Deer, Soldier, Threemile, Corral, Chimney and Sheep Creeks drain the area on the north and are tributaries to Camas Creek. None of these are perennial and during the summer all lose their entire flow by infiltration along their channels across the alluvial fans at the foot of the northern mountains. In late autumn, the creeks begin to discharge water into Camas Creek again as a result of increased precipitation on the mountains and decreased evapotranspiration on the prairie.

East of Blaine, Willow Creek is deeply incised into the older alluvium and has a perennial flow. A few ephemeral streams drain the prairie-facing slope of the Mount Bennett Hills on the south.

Climate

The climate of Camas Prairie is semi-arid with low precipitation, high evapotranspiration and large daily temperature fluctuations.

Precipitation records have been kept by the U. S. Weather Bureau at stations at Hill City (1923 to present), Fairfield Ranger Station (1949 to present), Soldier (1895-1910), and Soldier Creek Ranger Station (1910-1948). The Hill City station is considered to be representative of the climatic conditions of the prairie because of its location and its length of record. The lowest annual precipitation recorded at Hill City was 6.67 inches in 1939 and the highest was 24.70 inches in 1970. The average over a 49-year period is 15.15 inches.

Data compiled by the U. S. Weather Bureau show that January, February, March, May, November, and December are the months of greatest precipitation with each having more than one inch. July, August, and September are the months having the least precipitation, generally having less than one inch.

Temperature records show January to be the coldest month and July the hottest. Extremes recorded at Hill City are 102° F. and -44°F, with the annual average about 41° F.

Geology and Rocks

Camas Prairie is considered to be a structural depression that has been partially filled with alluvial material, mostly of Pleistocene age (Walton, 1962, p. 10; and Ross, 1970, p. 17). The alluvial material accumulated behind lavas of Pliocene and Pleistocene age that blocked the eastern outlet of the basin. It forms a series of broad alluvial fans which protrude outward from the mouths of the stream canyons that drain the northern mountains. Drillers' logs of wells indicate that the valley fill is at least 500 feet thick at Fairfield and one well reports about 750 feet of alluvial fill.

Relative to their effect on the occurrence and movement of ground water, the rocks of Camas Prairie and the surrounding mountains are of two general types: igneous and some consolidated sedimentary rocks which form the sides and valley floor of the structural depression; and valley fill, consisting of alluvial and lake deposits.

Igneous and Consolidated Rocks and Their Water-Bearing Properties

The rocks of the mountainous areas adjacent to the prairie are, for the most part, intrusive and extrusive igneous rocks of Cretaceous to Quaternary age. They presumably extend uninterruptedly beneath the valley fill. The igneous rocks bordering the prairie on the northwest, west and southwest are, in general, the rocks of the Idaho batholith and related rocks. These are medium- and coarse-grained crystalline rocks and include granite, quartz diorite, granodiorite and quartz monzonite. The ridges of the mountains on the north and northwest margins of the prairie are Challis volcanics and associated rocks such as andesite, dacite and rhyolite. The Mount Bennett Hills to the south are primarily silicic volcanic rocks such as dacite and latite and include beds of welded tuff and ignimbrites. The silicic volcanics are capped by basalt in places.

Carboniferous calcareous sandstone and limestone occur in a small area high in the northeastern part of the drainage basin in the upper part of the Willow Creek drainageway.

The rocks described above yield small to moderate amounts of ground water to wells and springs from weathered zones and complex systems of fractures, joints and crevices in what is otherwise relatively impermeable rock. Well yields are generally sufficient for domestic and stock use but rarely exceed 50 gallons per minute.

The ridges and rolling hills that bound the prairie on the east, west and south are composed of Snake River basalt of Pliocene to Recent age. The rocks are fine-grained to dense, basaltic lavas. The Snake River basalt extends from one to three miles beneath the valley fill northwestward from its exposed margin at the east end of the prairie. The uppermost Snake River basalt is known from a well at the eastern end of the prairie to be 188 feet thick. It is overlain by 92 feet of alluvial material and rests on silty clay at a depth of 280 feet.

A unit of unbroken basalt is relatively impermeable but porous and permeable zones may exist along joints, cooling cracks and between flows, and may yield large quantities of ground water to wells. Two wells near the eastern margin of the prairie in the Snake River basalt yield 1280 gallons per minute with 35 feet of drawdown and 1350 gallons per minute with 12 feet of drawdown respectively.

Valley Fill and its Water-Bearing Properties

Large quantities of sedimentary material, derived mainly from plutonic rocks and rhyolitic and andesitic lavas on the mountains to the north during Pliocene and Pleistocene times, accumulated in the Camas Prairie basin while Camas Creek was cutting through the lava barriers on the east. The sediments are poorly sorted and range in size from clay to boulders. The materials were transported into the basin by streams and sheet runoff, with the coarse debris being deposited near the foot of the mountains and the finer material being deposited farther out in the basin to the south.

The conditions of deposition were complex and the character of the valley fill changes from place to place, both horizontally and vertically. In general, the grain size is coarse near the foot of the northern mountains and becomes finer toward Camas Creek at the southern margin of the Prairie (Walton, 1962, p. 13; Piper, 1925, p. 10). The valley fill contains lenses and interfingering deposits of clay, silt and gravel.

Most of the drillers' logs of wells in the prairie report a clay layer averaging 90 feet in thickness between approximate depths of 120 and 210 feet below the surface. The extensive clay deposit suggests that a lake of considerable extent must have existed in the Camas Creek basin, probably during Pleistocene time.

Relief on the upper and lower surfaces of the clay is less than 50 feet and the thickness decreases at the southern margin of the prairie beneath Camas Creek.

The maximum thickness of the valley fill is unknown in most of the prairie. Two wells near Fairfield in the center of the prairie reportedly penetrated the valley fill and found bedrock at depths of 497 and 550 feet. However, Fairfield city well No. 4, approximately one-half mile from the shallower of these wells, was deepened in 1965 from an original depth of 352 feet to a depth of 760 feet and was still drilling in "brown, sandy clay" according to the well log. For this study the thickness of the valley fill is considered to be 350, 450 and 550 feet at Hill City, Corral and Fairfield respectively. These depths are considered to be minimum depths and were chosen because both artesian aquifers in the prairie are included and of the three wells deeper than 500 feet, two reportedly encountered "granite".

Sand and gravel in the valley fill are important aquifers in Camas Prairie and yield sufficient water for irrigation and large-scale uses. Permeable sand and gravel are found in two zones below the clay unit. Alternating beds of moderately permeable sandy silt, silt and clay lie above the clay unit. Immediately below the clay unit is the "upper artesian aquifer", consisting of fine- to medium-grained sand and some gravel interbedded with relatively thin lenses of clay. The thickness is variable but averages 50 feet.

Underlying the upper artesian aquifer are beds of sandy and silty clay that are relatively impermeable. The thickness of this unit varies, but averages about 90 feet. Below this unit is the "lower artesian aquifer" averaging about 50 feet in thickness. It is composed of permeable sand and gravel interbedded with lenses and layers of clay.

The two aquifers are fine-grained and their permeability is generally low. The average composition of the upper 250 feet of fill, from 26 wells in the prairie is 30% sand and 70% clay (Piper, 1925, p. 10).

Isolation of Study Region and Boundary Conditions for Model

Our finite-element program is designed for application to either a planar or axisymmetric type of flow problem. The planar option was used to model an east-west section through Camas Prairie. The section modeled is about 30 miles long and 375-550 feet in depth, and is oriented approximately parallel to Camas Creek which flows in a westerly direction along a trough in the piezometric surface.

To isolate the region of study, the various boundaries and boundary conditions had to be described. The topographic surface was used as the upper boundary because the depth to water averages less than 10 feet over the entire area. This approximation automatically eliminates any consideration of water storage in the unsaturated zone. This fact is significant because it requires that evapotranspiration be supplied only by the phreatic zone. The lower boundary, the impermeable basement, was determined from well drillers' logs and estimates by Piper (1925) and Walton (1962). The eastern, upstream, input end of the section was selected on the basis of the surface geology. The valley fill sediments terminate against basalt at the western end of the prairie. There are no wells from this point west to the drainage divide. The western boundary of the study region and section was placed as vertical and impermeable.

The eastern boundary was determined from well logs and what is known of the sub-surface geology. The valley fill terminates against basalt lava flows and relatively impermeable older alluvium. The eastern section boundary was, therefore, placed in the more permeable basalt, through which most of the underflow from the prairie occurs.

The discharge area was initially represented by assigning zero pressure to the 10 surface boundary nodes at the east end of the section. Pressures were not known for this vertical end boundary of the section, and it was, therefore, treated as impermeable in the program. This caused all the flow to come to the surface at the discharge nodes; flow at the vertical end boundary was necessarily vertical. This configuration was abandoned because flow through the end of the section, representing underflow from the prairie, was desired in the program output. The finally selected representation of the outflow end of the section was constructed by adding five columns of elements beyond the point where the flows were to be computed. This was done to avoid the impermeable-end effect. Zero pressure was assigned to the surface boundary node at the point where the section first intersects the perennial part of Camas Creek. The pressures on the surface boundary nodes downstream from this point were assigned values corresonding to the gradient of Camas Creek---about five feet per mile. The pressures on these nodes were, therefore, negative, representing feet of water below each node.

The Finite-Element Mesh for the Model

A geologic section was constructed along the line chosen for the model section and the finite-element mesh was developed from it. The geologic section was five hydrologic units in height. Each element of the mesh was made with height equal to the thickness of the unit it represented, thus element upper and lower boundaries corresponded to hydrologic unit upper and lower boundaries.

Each unit was made one element high. Because of the limitations on storage allocated for the mesh, element length to height was made in the ratio of 50 to 1, using the height of the first element in the thinnest hydrologic unit. Each element at the beginning of the mesh was made 2000 feet long, determined from the 40-foot thick unit at the west end of the section. The 2000-foot length was maintained for about 20 miles along the total length. In the part of the mesh corresponding to the last 10 miles, the discharge-outflow portion of the flow system, each element was divided into four elements. This step was taken to give more nodal points for computation in the area where the underflow from the prairie occurs and where the geology of the prairie is more complex.

Input to Model

The input to the model program consists of recharge in the form of annual precipitation, permeabilities of the various units, boundary conditions and the geometric positioning of the finite-element mesh nodal points.

Precipitation

U. S. Weather Bureau records for the Hill City station were selected as being typical of the prairie and the 49-year average of 15.15 inches was used. An additional 2 inches was added as being due to the effects of the topography of the higher surrounding area, resulting in the figure 17 inches for annual precipitation.

Because recharge occurs over only a portion of the prairie it was necessary to separate the recharge and discharge areas to determine the volume of water to use as input. The final result was based on a combination of three different methods. First, during the summer of 1970, a field map was constructed by noting such things as water in the grader ditches, cattails, marshy areas in the fields, clumps of willows and aspens---in short, anything that might indicate a particular area was showing a net gain or loss of water from the ground-water body.

Second, maps were made of the piezometric surface and the water table for July, 1970, and these were compared. Areas where the water table was at a higher altitude than the piezometric surface were considered recharge areas, and, conversely, areas with the piezometric surface higher were considered discharge areas.

Third, infrared film was used to take low-oblique stereo photos of the area. The stereo-pair slides were used to further delineate areas of discharge by the infrared reflectance characteristics of actively transpiring vegetation.

The recharge-discharge boundary was established for late June-early July, 1970, and the area of recharge determined to be approximately 80 square miles, or 51,200 acres. The recharge occurs mostly on the northern and western margin of the prairie between the Boise base line and the exposed igneous rocks of the higher areas. Precipitation on the igneous rock was treated as runoff since these rocks are practically impermeable.

To use the annual precipitation as input to the planar flow section required that it be applied to the up-gradient end of the section. This was accomplished by using the westernmost portion of the recharge area and applying the entire volume of recharge water to this smaller area through which the model section was taken. The area used is about 2.5 miles by 1.5 miles and is approximately rectangular. The flow within this area is nearly all parallel to the model section, so applying the entire recharge volume to this area is felt to be justified.

The annual amount of water available is 17 inches on the intake area of 51,200 acres, or about 72,200 acre-feet. The recharge area through which the model section is taken is about 3.75 square miles or 2,400 acres. The 72,200 acre-feet applied to this area is equivalent to a depth of about 30 feet of water. This method of recharging the model requires that this depth of water be used as the input for the model section.

Permeability

Although the program will accept anisotropic material and inclined units, the units were considered individually homogeneous and isotropic, as well as horizontal, for this model. This was done partly because of lack of data, especially for the deeper units, and partly in an attempt to avoid storage problems within the program. The permeabilities are expressed as velocities, in this case, centimeters per year for convenience in output calculations.

The only available pump-test data were from one pumping test run by Walton in 1957. Transmissibility of a 126-foot interval of the lower artesian aquifer was computed to be about 30,000 gallons per day per foot. This gives a permeability at this location of 238 gallons per day per square foot or 35,500 centimeters per year for the lower artesian aquifer.

Walton (1962, p. 19) assumed the transmissibility of the 126-foot interval to be typical of the entire thickness below the clay unit, including both artesian aquifers and the silty, sandy, clay unit that separates them (all units as discussed previously). He assigned this entire thickness a transmissibility of 70,000 gallons per day per foot. Walton also estimated the amount of leakage and underflow from consideration of the flow through the upper and lower artesian aquifers between two sets of isopiestic contours. From this estimate he obtained the vertical field permeability of the confining clay unit to be 0.2 gallons per day per foot. This figure, converted to 298 centimeters per year was used as the permeability for the clay unit and the unit between the artesian aquifers was assigned an initial permeability of approximately ten times that of the clay, i.e., 3000 centimeters per year.

Using Walton's estimate of transmissibility for the total thickness below the clay and the above estimate for the unit between the artesian aquifers, an initial permeability of 726 gallons per day per square foot or 1,080,000 centimeters per year was computed for the upper artesian aquifer. A permeability for the surface unit of the prairie was computed from 3-hour pumping test which we ran on a new, 120-foot well. The value obtained was 19.1 gallons per day per square foot or 28,400 centimeters per year.

The basalt unit forming the eastern boundary of Camas Prairie has been penetrated by one well, and it has several other wells drilled into it. Data from these wells suggest that the upper 180-200 feet of the basalt have a transmissibility of roughly three times that of the combined artesian aquifers (Walton, 1962, p. 25). Using a transmissibility of 210,000 gallons per day per foot and a thickness of 200 feet results in a permeability of 1,050 gallons per day per square foot or 1,560,000 centimeters per year. The basalt below the 200-foot upper permeable part was arbitrarily assigned a low permeability of 30 centimeters per year to make it relatively impermeable and to make it a part of the model.

Location of Mesh Nodes

In order to describe the location of the nodes a coordinate system was constructed. A zero datum plane was placed at an elevation of 4400 feet above mean sea level, about 700 feet below the highest elevation along the section. All node elevations were picked from the geologic section and were referred to this datum. Horizontal distances were measured eastward from the west end of the section.

Input to Model

Because the recharge to the area occurs downward through the surface of the prairie it was considered realistic to apply the input to the model section at the upper surface. The thirty feet of water, equivalent to the volume of precipitation on the recharge area was applied to the first eight surface nodes at the west end of the section. These nodes, numbered 6, 12, 18, 24 and 30, represent distances eastward along the model section of 0, 2000, 4000, 6000 and 8000 feet respectively. Eight thousand feet is approximately that part of the section that is recharge area, or the distance between the impermeable basalt to the west and the area of flowing wells to the east.

Output from the Program

The output of the program consists of a listing of all input data, including each element and each node of the finite-element mesh with the respective coordinates. The output of the computations is in two parts. The first is a tabular presentation of each node in sequence with the corresponding pressure and potential. Pressure has the units of the input pressures, in this case, feet of water, and potential is given as a decimal representing the percentage of the difference between values supplied as input on the control card.

The second part of the output is a tabular presentation of each element in sequence, the coordinates of the program-placed center of the element, flow as a velocity in both the X' or 1 and the Y' or 2 direction, angle of inclination if the units are not horizontal, resultant flow velocity from the center of each element and resultant flow direction at the center of the element with respect to the positive X or R direction.

Results

The output of the program was utilized in two different ways. First, 12 nodes has been put into the finite-element mesh at various distances along the model section. These nodes were in addition to the regular uniformly-spaced nodes and represent checkpoints in the geologic section. The checkpoints are bottom of casing at some locations and bottom or mid-point of an uncased interval in others, of wells near the line of section. In these checkpoint wells the artesian pressure or water level is known from field measurements. The computed values of pressure at the checkpoints were compared to the measured values as an indication of how well the model section fit the actual situation. These data are presented in Table V-1.

Five of the 12 checkpoints are from wells in the upper artesian aquifer, which is the most developed aquifer in the prairie. The computed value for

TABLE V-1

Comparison of Measured Heads with Computed Values

Checkpoint	Distance From East End Of Section, Ft.	Depth	Casing Depth	Head, Ft. Measured	Head, Ft. Computed	Head, Ft. Difference, With Respect To Measured
1	12,000	250	250	255	265	+10
2	24,000	60	20	60	52	-8
3	28,000	170	170	172.5	162	-10.5
4	32,000	300	---	305.9	288	-17.9
5	46,000	180	---	186	189	+3
6	48,000	54	54	53*	62	+9
7	58,000	210	195	212.5	214	+1.5
8	72,000	220	220	223.5	216	-7.5
9	86,000	218	108	220.7	239	+19.7
10	108,000	434	434	439	436	-3
11	136,000	263	101	248	245	-3
12	138,000	155	122	137	136	-1

*Adjusted from 45 Sect. to compensate for altitude difference at well and at line of section.

5 wells are within 10% of the measured values and with 5% for 3 of them. Computed values for 3 wells in the lower artesian aquifer and 2 wells in the basalt aquifer are all within 6% of the measured values.

In addition to the above, 2 wells in the water-table aquifer were included because the shallow water table is maintained partly by leakage upward through the clay unit. These 2 wells show the greatest discrepancy between computed and measured values as would be expected, since the model represents essentially the deeper artesian system and the hydraulic connection to the water table is only indirect. Values for both wells were about 13% different than the measured values. These differences were considered acceptable, considering that a one-foot difference in a shallow well represents a larger percentage than in a deeper well.

The second way in which the program output was used was in computation of quantitative results for amount of flow through the end of the section. The volume of water available annually for recharge was applied to an area of approximately 2400 acres at the western end of the section and the model section was carried through this area. The section is of unit width; in this case it is one foot wide. The surface area of the model section through which the input is applied is about 8000 feet by 1 foot, or 0.184 acres. The 30 feet of water on this area is a volume of 5.52 acre-feet.

Elements 526, 527 and 528 were placed in the mesh at the end of the actual model. These represent the point along the section where Camas Creek has cut a canyon deep enough to be perennial. Elements 528-549 were added to reduce the boundary effects of the impermeable end of the section. Flows were computed on a volume basis, converted to equivalent feet of water on the recharge area at the input end of the section and referred to the initial 30 feet of water input for comparison.

Element 526 is 300 feet in height and has a resultant flow velocity of 0.0647 centimeters per year. This represents such a small annual flow that it was disregarded, since most of the flow occurs through the elements representing the more permeable basalt.

Element 527 is 100 feet in height, has a flow velocity in the 1 or X direction of 3355.5 centimeters per year (equivalent to 0.253 acre-feet), is 1000 feet in length and has a flow velocity in the 2 or Y direction of 42.3 centimeters per year (equivalent to 0.031 acre-feet).

Element 528 has an average height of 74 feet, has a flow velocity in the 1 or X direction of 3382.4 centimeters per year equivalent to 0.189 acre-feet, is 1000 feet in length and has a flow velocity in the 2 or Y direction of 93.6 centimeters per year equivalent to 0.071 acre-feet.

These figures give a total outflow at this point in the section of 0.544 acre-feet equivalent to about 3 feet of water on the input end of the model section. This represents the part of the 30 feet of water input that is underflow from the prairie.

Walton (1962, p. 20, 21) computed underflow and leakage at a location slightly west of where the model section ends and concluded that leakage and underflow were nearly equal. Assuming this to be true and using the figure computed here for underflow gives a figure of 6 feet of water for underflow and leakage combined. This figure also represents the amount of the 30-foot input that is annual recharge to the artesian aquifers since the recharge must balance the underflow and leakage to maintain the aquifers.

Camas Creek is perennial in the eastern end of the prairie and the flow, adjusted to the 1952-1967 base period, is given by the U. S. Geological Survey as 165 cubic feet per second. The only gaging station for the prairie is located downstream from the actual prairie in the basalt canyon and below the point where the perennial flow from Willow Creek enters Camas Creek. To estimate the contribution to streamflow from the recharge area, this figure was applied to the recharge area and the volume represented was referred to the section input. This amounts to 6.1 feet on the section.

Therefore, of the 30 feet of water applied to the model as recharge, representing the equivalent of 17 inches of water on 80 square miles of recharge area, underflow and leakage plus runoff to streamflow account for 12.1 feet. The remaining 17.9 feet is assumed to be lost by evapotranspiration.

These figures in terms of the 17 inches available annually on the Camas Prairie recharge area are: underflow and leakage 3.4 inches, runoff and streamflow 3.5 inches and evapotranspiration 10.1 inches. Evapotranspiration, therefore, amounts to about 60% of the water available to the recharge area.

Two additional inputs were used representing approximately a 20% increase and a 20% decrease in the annual precipitation, giving inputs of 35.2 and 24.4 feet of water respectively. The computed underflow from the model in both cases represented a change of less than 0.1 foot of water from the results using the 30-foot input for average annual precipitation. This indicates that annual changes in precipitation do not greatly affect the artesian aquifers in any one year, probably because of the large volume and areal extent of the aquifers.

Conclusions

Based on the results presented, the following conclusions are drawn:

1. From comparison of the actual values of water levels measured in the field with the computed values from the model, the model is considered an acceptable representation of the actual conditions. In this first attempt to model the complex ground-water system with a planar flow model, a number of simplifications were necessarily introduced. Some of these could undoubtedly be made more realistic with further work.

2. Flow quantities are considered to be of the right magnitude. The input for precipitation is considered accurate and valid. The permeabilities are for the most part estimates based on the limited amount of data available. The assumption of isotropy and homogeneity are probably the least realistic of those made for the inputs. The clay unit, for example, is probably more permeable horizontally than vertically, and it is known that the sediments become finer-grained southward from the foot of the mountains. If more data become available with regard to permeability values, the input permeabilities can be made more realistic and refine the output. At present, the cost of obtaining permeability data limits the capabilities of the model.
3. A model developed by the finite-element technique can have wide applications where pressure, flow direction and flow velocity can be of use at various points, since these quantities are computed for all elements in the mesh. This can be of value in ground-water studies of flow systems and water budgets as well. The technique is also applicable to problems such as flow through the sides of unlined irrigation canals. In most of these cases, however, cost of obtaining reliable permeability data would be a limiting factor.
4. Once a finite-element model of a system is developed, any of the input parameters may be readily modified or changed if new information is made available or conditions change. Past and future conditions may be simulated within a system. In this study, for example, the changes in annual precipitation were introduced by punching 6 cards to replace those originally used.
5. Inferences can be developed or verified by the use of a finite-element model. In the example used here of changing the annual precipitation input, it appears that annual changes are most likely to be reflected in shallow, water-table and surface phenomena such as water-levels in shallow wells, surface runoff and streamflow, and possibly, evapotranspiration in extreme cases.

6. At its present state of development, the program used to generate the model has storage limitations that affect the size of the problem that can be handled. This can be partly compensated for by using larger elements but there is a risk of some smoothing or averaging effects. This is particularly true near boundaries of the mesh and between units having different characteristics within the mesh. This effect should be examined but storage limitations prevented it in this study.

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APPENDIX A

Procedure for Cation Exchange Capacity using Calcium at a Neutral pH

1. Place 3-5 grams of 2.0 mm air-dried soil (weight must be accurately determined to 2 decimal places) in a 100-ml centrifuge tube and add 50 ml of 1 N $NaOA_c$ (pH 5.0). Stir with a policeman-tipped rod.

2. Digest in a 90°C water bath for 30 minutes with intermittent stirring.

3. Remove salts by centrifugation (2000 rpm) and decantation. Repeat procedure twice, omitting the digestion unless the soil is known to be calcareous.

4. Removal of organic matter to compare ion exchange of mineral material versus total soil:

   a. Transfer sample to 250 ml beaker with 10 ml of distilled water.

   b. Add 5 ml of 30% H_2O_2, cover with a watch glass and heat cautiously. If the reaction gets violent, remove beaker from hot plate and quiet with a stream of water from a wash bottle.

   c. When the reaction is quiet, additional 5 ml increments of 30% H_2O_2 are added, one at a time, and the digestion continued until all orgamic matter is destroyed. Never carry the evaporation below 5 ml.

5. The acidified soil sample (after transfer back to the centrifuge tube if the H_2O_2 procedure has been used) is washed twice with neutral 1 N $NaOA_c$.

6. Wash five times with 1 N $CaCl_2$ to saturate using the sequence; micro-mixer, centrifuge (2000 rpm), decant, $CaCl_2$, micro-mixer, etc.

7. Remove excess salt with five washings using 80% acetone (same sequence as in 6 above). Check for chloride with 0.1 M $AgNO_3$ in last wash.

8. Replace calcium using five washings with neutral or 1 N NH_4OA_c (if flame photometry or atomic absorption is to be used). Save and combine all washings.

9. Determine calcium content by atomic absorption.

APPENDIX B

Method for Extractable Metallic Cations

A. Extraction

1. Place weighed 5 gm sample of air-dried (35°C) soil in a 50 ml round-bottom narrow-neck centrifuge tube.

2. Add 33 ml of neutral 1 N NH_4OA_c, stopper, shake for five minutes and then centrifuge until supernatant is clear (about 5 minutes at 2000 rpm).

3. Decant supernatant into 100 ml volumetric flask.

4. Extract twice more with 33 ml portions of NH_4OA_c decanting supernatant into same volumetric. Bring volume to 100 ml with NH_4OA_c.

B. Determinations

1. Run Ca, Mg, Na, and K by atomic absorption.

2. Run a reagent blank on the NH_4OA_c.

APPENDIX C

Method for Organic Matter in Soils

A. General

This method excludes elementary carbon and most biologically non-oxidizable forms of carbon.

B. Reagents

1. 85% H_3PO_4
2. Solid NaF
3. Conc. H_2SO_4 (98%)
4. Standard 1 N $K_2Cr_2O_7$ (49.04 gm/liter)
5. Diphenylamine indicator (.5 gm dissolved in 20 ml water + 100 ml conc. H_2SO_4)
6. 0.5 N Ferrous ammon. sulfate (196 gm dissolved in 800 ml water + 20 ml H_2SO_4 - dilute to 1 liter). Must be standardized against dichromate daily.

C. Procedure

1. A 0.50 gm sample is placed in a 500 ml flask; add 10.0 ml of 1 N dichromate mix and add 20 ml of conc. H_2SO_4, mix. Let stand for 30 minutes.
2. Dilute to 200 ml; add 10 ml H_3PO_4, 0.2 gm of NaF and 1.5 ml of diphenylamine indicator.
3. Titrate with ferrous ammon. sulfate to brilliant green end-point. If over 8 of the 10 ml of chromic acid has been consumed, repeat test using a smaller soil sample.
4. Calculation:

$$\% \text{ organic} = 10.3\ (1 - \frac{T}{S})$$

where S = standardization blank titration, ml

T = sample titration, ml

APPENDIX D

Soil Nitrate Nitrogen NO_3-N

Monograph No. 9, "Methods of Soil Analysis", American Society of Agronomy, Phenoldisulfonic Acid Method 84-5.3, p. 1216, 1965.

Procedure

1. Weigh 25 gm of soil into an extraction flask (250 or 300 ml Erlenmeyer wide mouth).

2. Add 100 ml of $CaSO_4$ solution to the flask.

3. Shake for 15 minutes on the mechanical shaker at the variable speed indicator setting of 1.

4. Filer through S & S 605-18.5 cm filter paper into receiving flask.

5. Transfer a 10 ml aliquot to a 3" casserole dish.

5a. Add 1 ml of saturated $CaCO_3$ solution before placing on steam bath.

6. Evaporate to dryness of steam bath and be careful that area is free of HNO_3 fumes.

7. Cool dishes.

8. Prepare a reagent blank beginning at step No. 7. Use this blank to adjust the colorimeter to 100% transmittance.

9. Add 2 ml phenoldisulfuric acid rapidly from a burette. Rotate dish gently so the phenoldisulfuric acid is in contact with the entire residue.

10. Let set for 10 minutes.

11. Add 50 ml of distilled H_2O with automatic pipetting machine and stir with a glass stirring rod.

12. Add 10 ml of concentrated NH_4OH slowly with stirring until solution is alkaline (as indicated by development of yellow color or use of pH paper).

13. Transfer to a large Bausch and Lomb colorimeter tube.

14. Measure the amount of NO_3 on the Bausch and Lomb Spectromic 20 colorimeter with a 480 mμ filter.

15. Report as ppm NO_3-N.

Table D-1. Table NO_3-N: Standards to be used to establish a working curve and standards to be run routinely to continuously check reagents.

Add 3 ml phenoldisulfonic acid to every standard as outlined in the procedure and NH_4OH as to all samples. Start all standards at Step 5 in the procedure.

$$\text{ppm } NO_3\text{-N} = \frac{NO_3\text{-N } \mu g \text{ in solution}}{\text{gm soil in aliquot}} = \frac{NO_3\text{-N } \mu g \text{ in solution}}{2.5 \text{ gm soil}}$$

ml of stock solution	ppm NO_3-N	pp4m NO_3-N	
0	0	0	XX
1	4.0	16.0	
2	8.0	32.0	XX
3	12.0	48.0	
4	16.0	64.0	X
5	20.0	80.0	
6	24.0	96.0	XX
7	28.0	112.0	
8	32.0	128.0	X
9	26.0	144.0	
10	40.0	160.0	

NOTE: Those standards marked X are to be run every week or whenever a new reagent solution is prepared and used; those marked XX are to be run daily.

Reagents

1. Calcium sulfate (gypsum $CaSO_4 \cdot 2H_2O$): Reagent-grade powdered. Dissolve 40 gm of $CaSO_4$ in distilled water and make to final volume of 18 liters with distilled water. This is approximately a saturated gypsum ($CaSO_4$-$2H_2O$) solution. To make 20 liters add 45 gm of $CaSO_4$ to distilled water and make to 20 liters. In soils that contain chlorides (Cl) add silver sulfate ($AgSO_4$) to the calcium sulfate solution at 1 gm 1 liter of solution---18 liters add 18 gm; 20 liters add 20 gm.

2. Phenoldisulfonic acid: Dissolve 25 gm of pure white phenol in 150 ml of concentrated H_2SO_4 (sp. gr. 1.84) in a 500 ml Erlenmeyer. Add 75 ml of fuming H_2SO_4 (13% SO_3), mix the solution and place the flask (loosely stoppered) in boiling water or steam bath for 2-4 hours. Store the resulting solution of phenoldisulfonic acid in a glass stoppered amber bottle.

If no fuming sulfuric acid dissolve 25 gm pure phenol in 225 ml of concentrated H_2SO_4 and heat on a steam bath or in boiling water for 6 hours.

3. Concentrated ammonium hydroxide solution: Use reagent grade NH_4OH (sp. gr. 0.89 to 0.90). Can use dilute solution of 1 liter NH_4OH with 1 liter distilled H_2O (1:1).

4. Standard nitrate nitrogen solution: (10 μg NO_3-N/ml). Dissolve 0.1443 gm of oven-dried KNO_3 in distilled H_2O and dilute to 2 liters.

5. Calcium carbonate: Make a saturated solution of calcium carbonate by adding 25 gm of calcium carbonate per liter.

APPENDIX E

Sodium Bicarbonate Extractable Phosphorus

Olsen, S. R. et al., "Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate", U.S.D.A., Circular 939, 1954.

Olsen, S. R., and F. S. Watanche, "Test of an Ascorbic Acid Method for Determining Phosphorus in Water and $HaHCO_3$ Extracts from Soil", Soil Science 29:677, 1965.

Procedure

1. Weigh 5.0 gm of soil into an extraction bottle.

2. Add 100 ml of 0.5 M $NaHCO_3$ extraction solution.

3. Shake on mechanical shaker at speed setting of #3 for 30 minutes.

4. Filter through S & S 605-15 cm filter paper into receiving flask.

5. Transfer a 2.0 ml aliquot to a large Bausch and Lomb colorimeter tube containing 3.0 ml of distilled H_2O.

6. Add 4 drops of 5 N H_2SO_4 and mix thoroughly. See note below.

7. Add 1.0 ml of Reagent B and mix thoroughly.

8. After standing for 30 minutes determine the transmittance of the solution of the Bausch and Lomb Spectronic 20 colorimeter using a 690 mμ filter. This color is stable for 24 hours.

9. Report as ppm P in soil extractable with 0.5 M $NaHCO_3$.

NOTE: The pH of the resulting solution should be about pH 5.0 or the resulting phosphorus determination will be in error due to the pH influence on the color development of the reducing agent. The amount of acid needed can be determined by titrating a large amount of bicarbonate solution using P-nitrophenol as an indicator, changes from yellow to clear at pH 4.95.

Table E-1. Standards used for establishing an $NaHCO_3$ phosphorus working curve and standards to be used for checking reagents

$$\text{ppm P in soil} = \frac{\mu g \text{ P in solution}}{\text{gm soil in aliquot}} = \frac{\mu g \text{ P in solution}}{0.1 \text{ gm}} = \mu g \text{ P} \times 10$$

To all solutions add 3 ml of distilled water, 4 drops of 5N H_2SO_4 and 0.1 ml of Reagent B as indicated in procedure beginning with Step 5. Use ml of each of the following solutions:

0.5 µg P/ml	1.0 µg P/ml	2.5 µg P/ml	ml $NaHCO_3$	Soil ppm P	
0	0	0	2	0	XX
1	0	0	1	5	
2	0	0	0	10	XX
1	1	0	0	15	
0	2	0	0	20	XX
0	0	1	1	25	
1	0	1	0	30	X
0	0	2	0	50	X

NOTE: The standards marked X are to be run weekly and when new reagents or solutions are used, those markes XX are to be run daily.

Reagents

1. 0.5 M $NaHCO_3$---sodium bicarbonate: Dissolve 757 gm of $NaHCO_3$ in distilled water in an 18 liter container. Dilute to approximately 17 liters with distilled water and check pH with pH meter. If needed, adjust to pH 8.5 with 1 M NaOH (40 gm/liter) approximately 450 ml. Make volume to 18 liters with distilled water. This solution should be checked every month for pH and not used if more than three

months old. To make 20 liters use 841 gm sodium bicarbonate, and it will require approximately 334 ml of (M NaOH to adjust pH).

2. Reagent A: Dissolve 12 gm of ammonium molybdate $(NH_4)_6\ Mo_7O_{24}\cdot 4H_2O$ in 250 ml of distilled water.

Dissolve 0.2908 gm of antimony potassium tartrate K (SbO) $C_4H_4O_6\cdot\frac{1}{2}H_2O$ in 100 ml of distilled water.

Add these two solutions to 1000 ml of 5N H_2SO_4 (148 ml conc. H_2SO_4 diluted to 1000 ml with distilled water) and mix thoroughly, then dilute to 2 liters with distilled water. Store in a dark bottle in a cool-dark place.

3. Reagent B: Prepare fresh daily. Dissolve 1.056 gm of ascorbic acid in 200 ml of Reagent A and mix well. Not stable for more than 24 hours.

4. 5N H_2SO_4: Dilute 148 ml of concentrated H_2SO_4 (sp. gr. 1.84) to 1000 ml with distilled water and mix thoroughly.

5. Standard phosphorus stock solution (50.0 μg P/ml): Dissolve 0.2194 gm of oven-dried KH_2PO_4 in distilled water and dilute to 1 liter with extraction solution 0.5 M $NaHCO_3$.

6. Standard phosphorus solution (0.5 μg P/ml): Dilute 10 ml of standard phosphorus stock solution (50 μg P/ml) to 1 liter with extraction solution 0.5 M $NaHCO_3$.

7. Standard phosphorus solution (1.0 μg P/ml): Dilute 20 ml of standard phosphorus stock solution (50 μg P/ml) to 1 liter with extraction solution 0.5 M $NaHCO_3$.

8. Standard phosphorus solution (2.5 μg P/ml): Dilute 50 ml of standard phosphorus stock solution (50 μg P/ml) to 1 liter with extraction solution 0.5 M $NaHCO_3$.

APPENDIX F

Figures

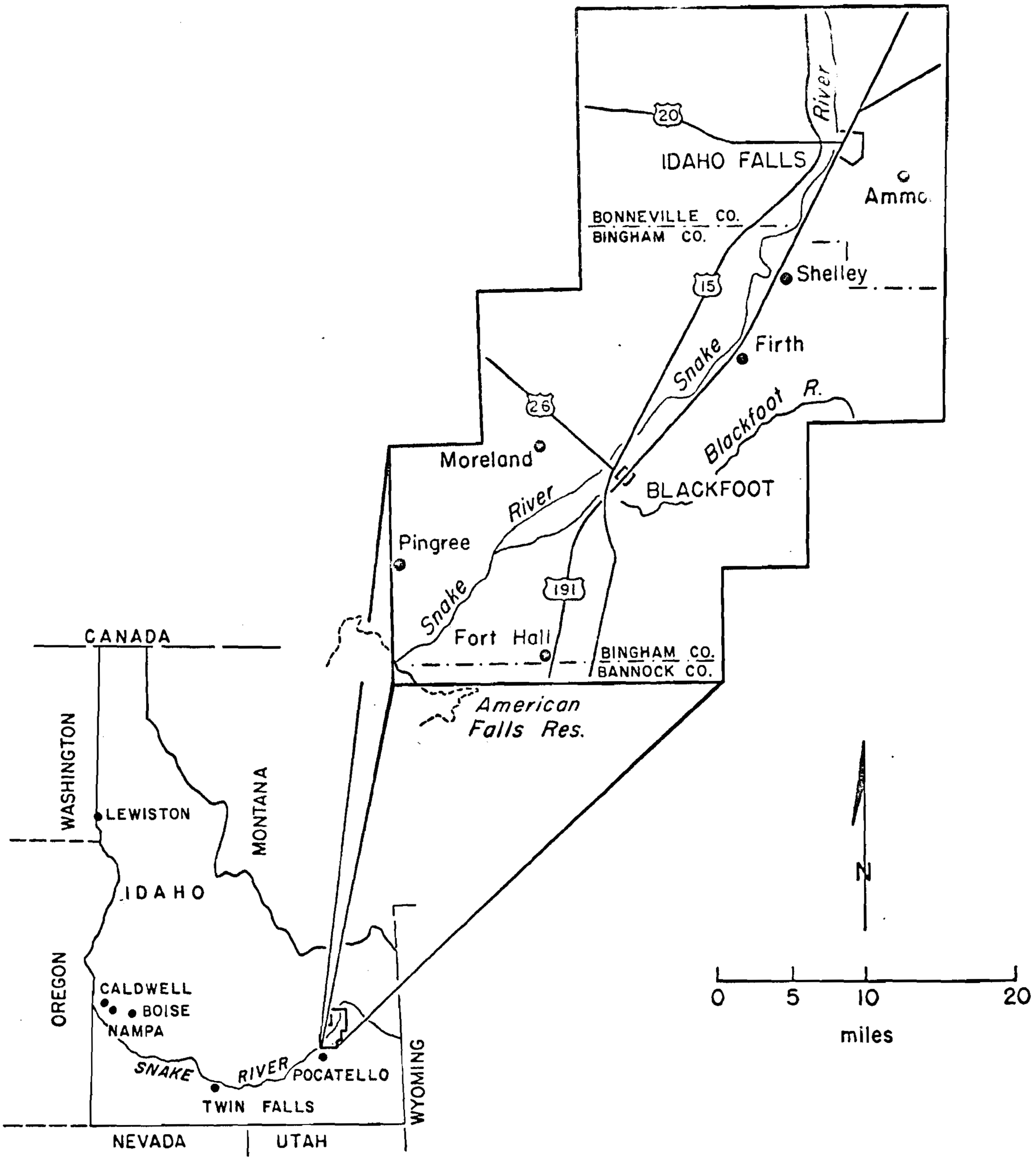


FIGURE II-1. Index Map—Idaho Falls-Blackfoot area, Idaho.

FIGURE II-2. General setting of waste-water reuse study.

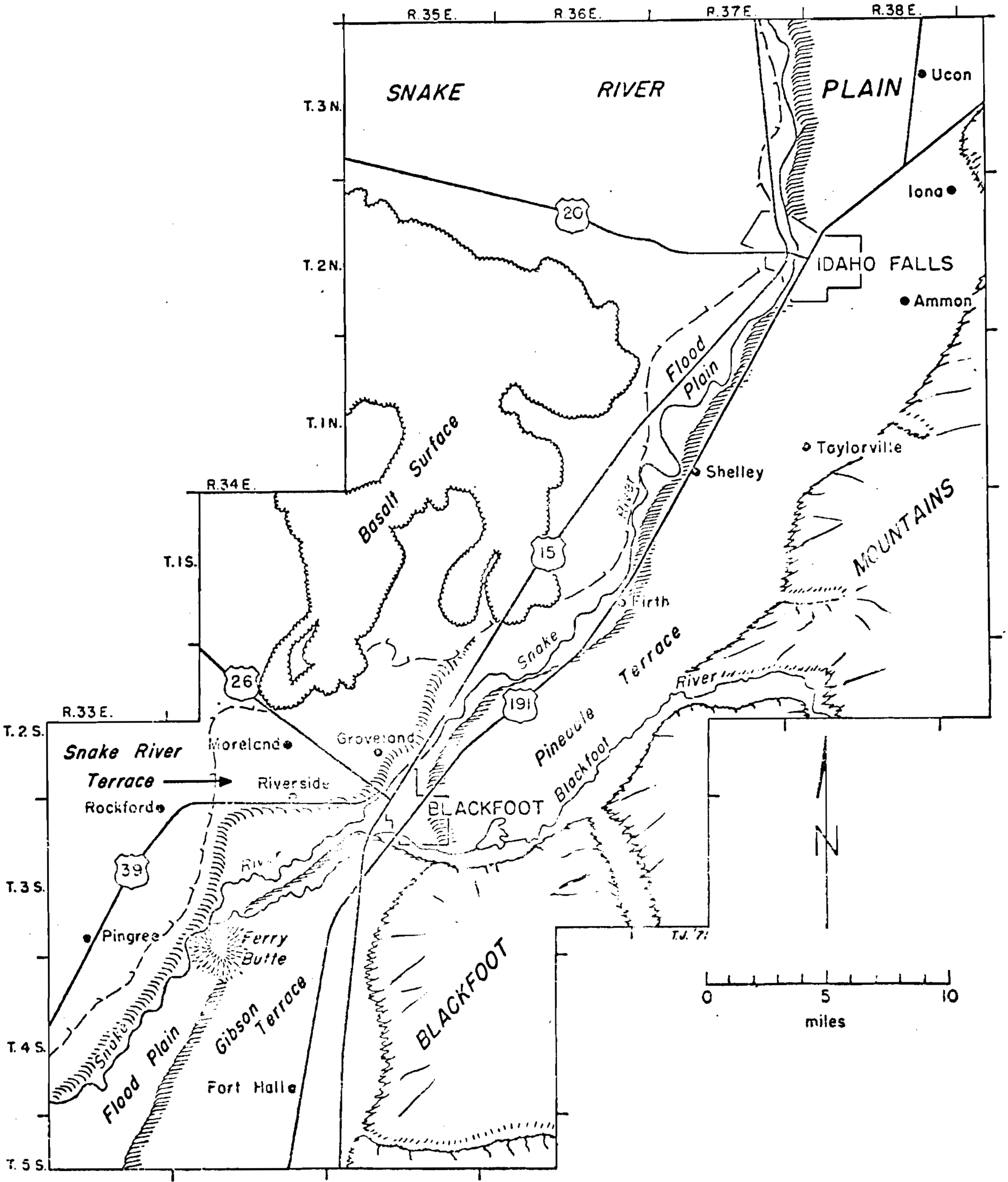


FIGURE II-3. Depth to water table.

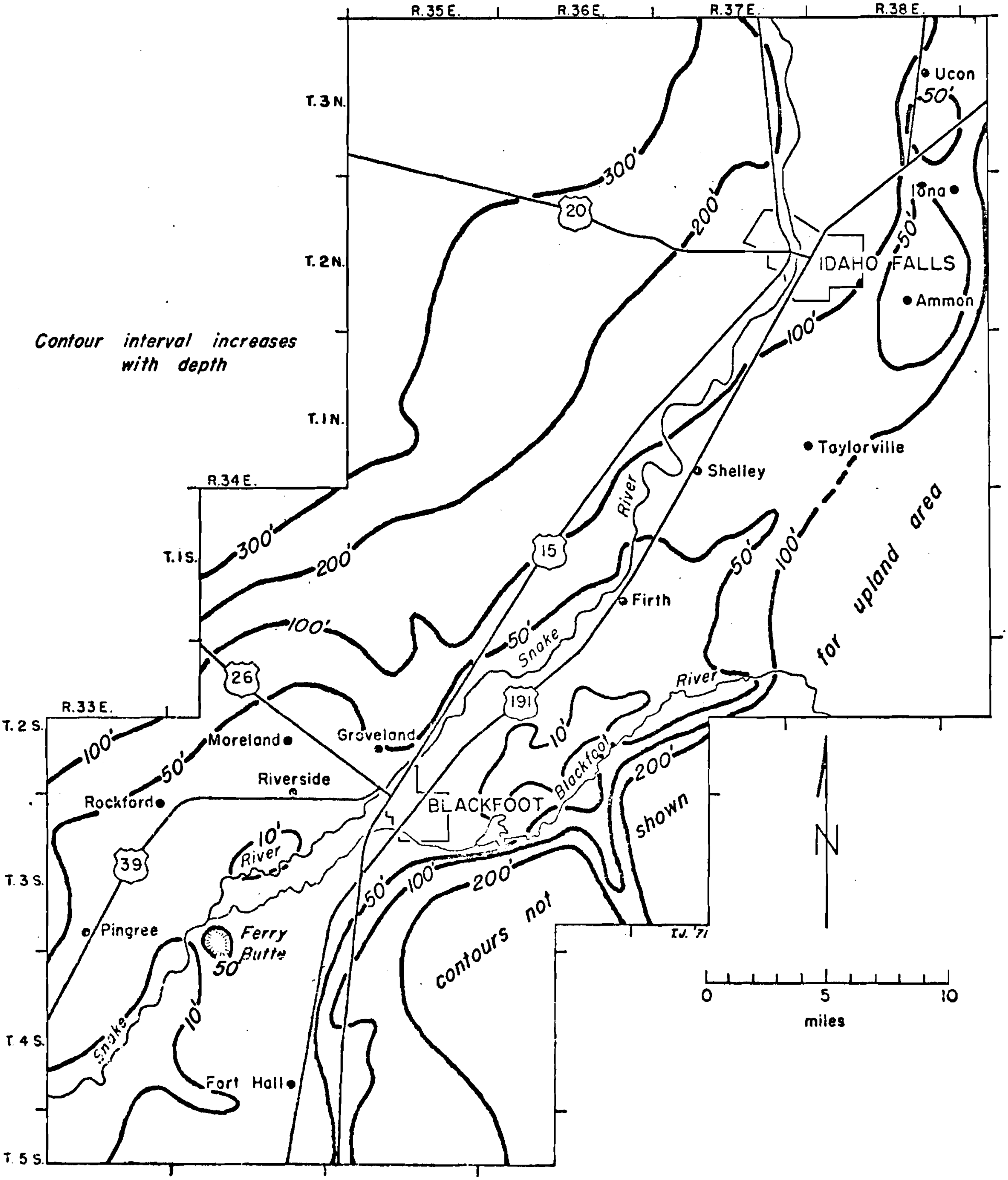


FIGURE II-4. Thickness of unconsolidated material.

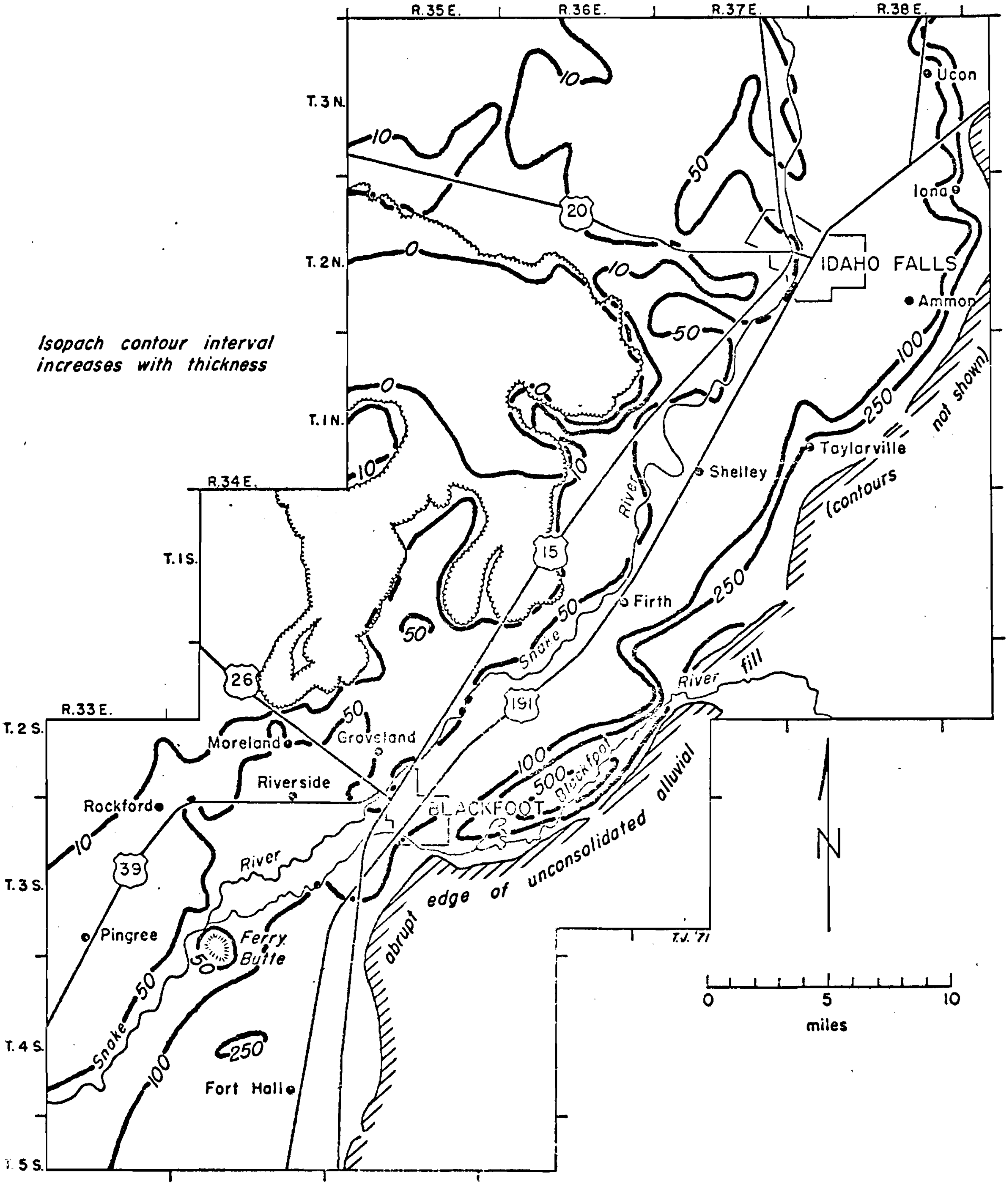
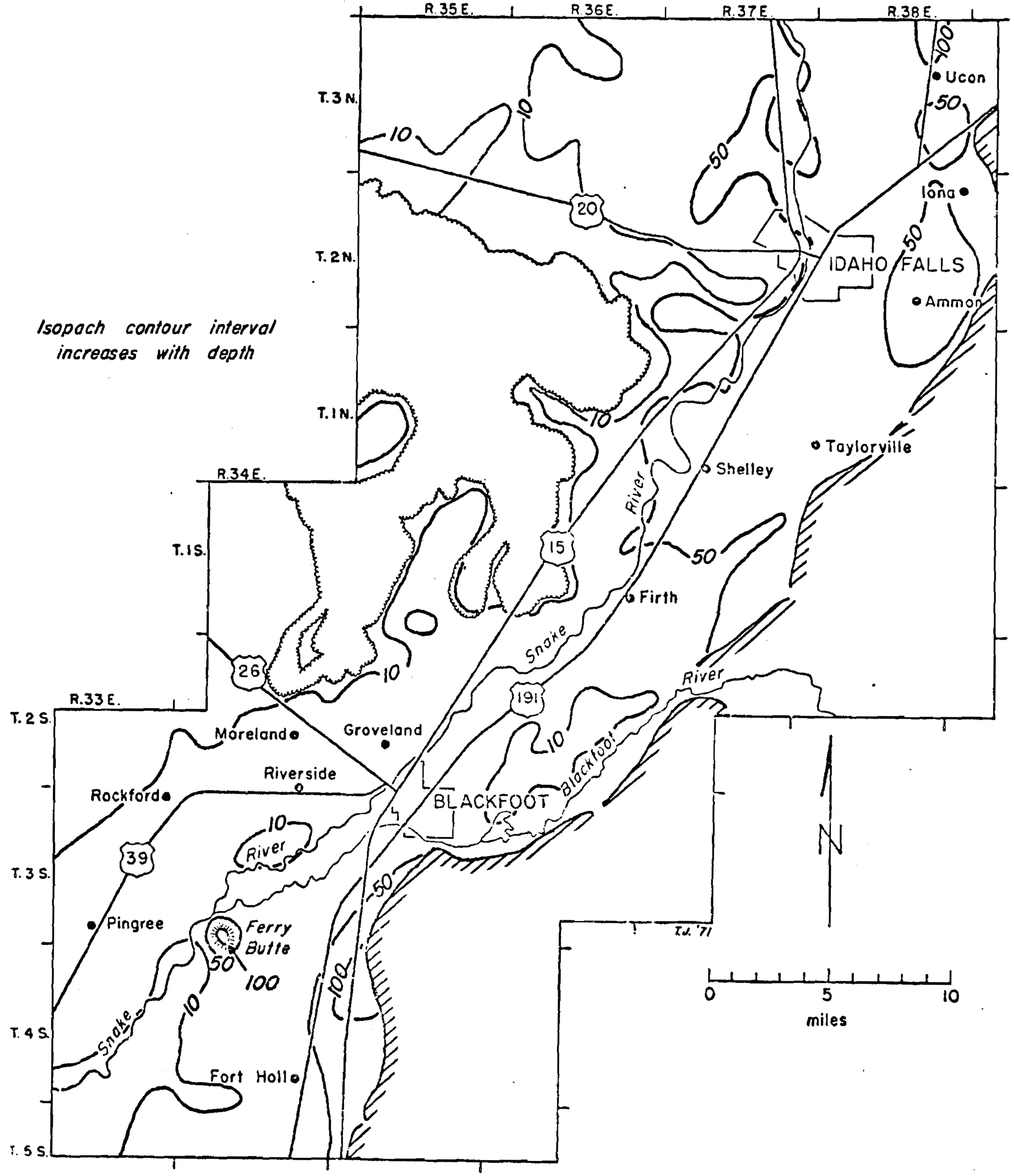


FIGURE II-5. Thickness of unconsolidated, unsaturated material.



Isopach contour interval increases with depth

FIGURE II-6. Disposition of soils with desirable filtration characteristics.

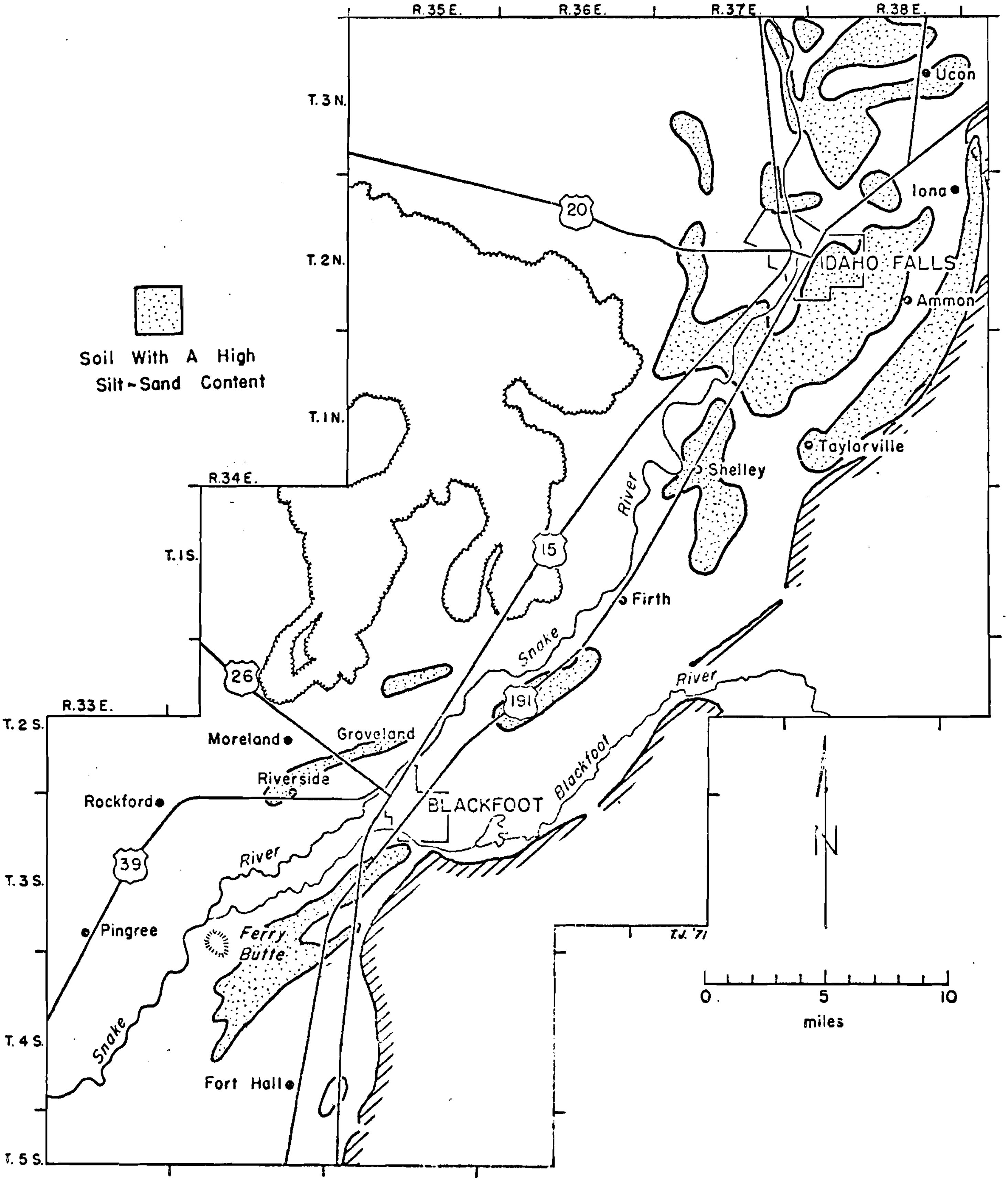


FIGURE II-7. Geologic and hydrostratigraphic units.

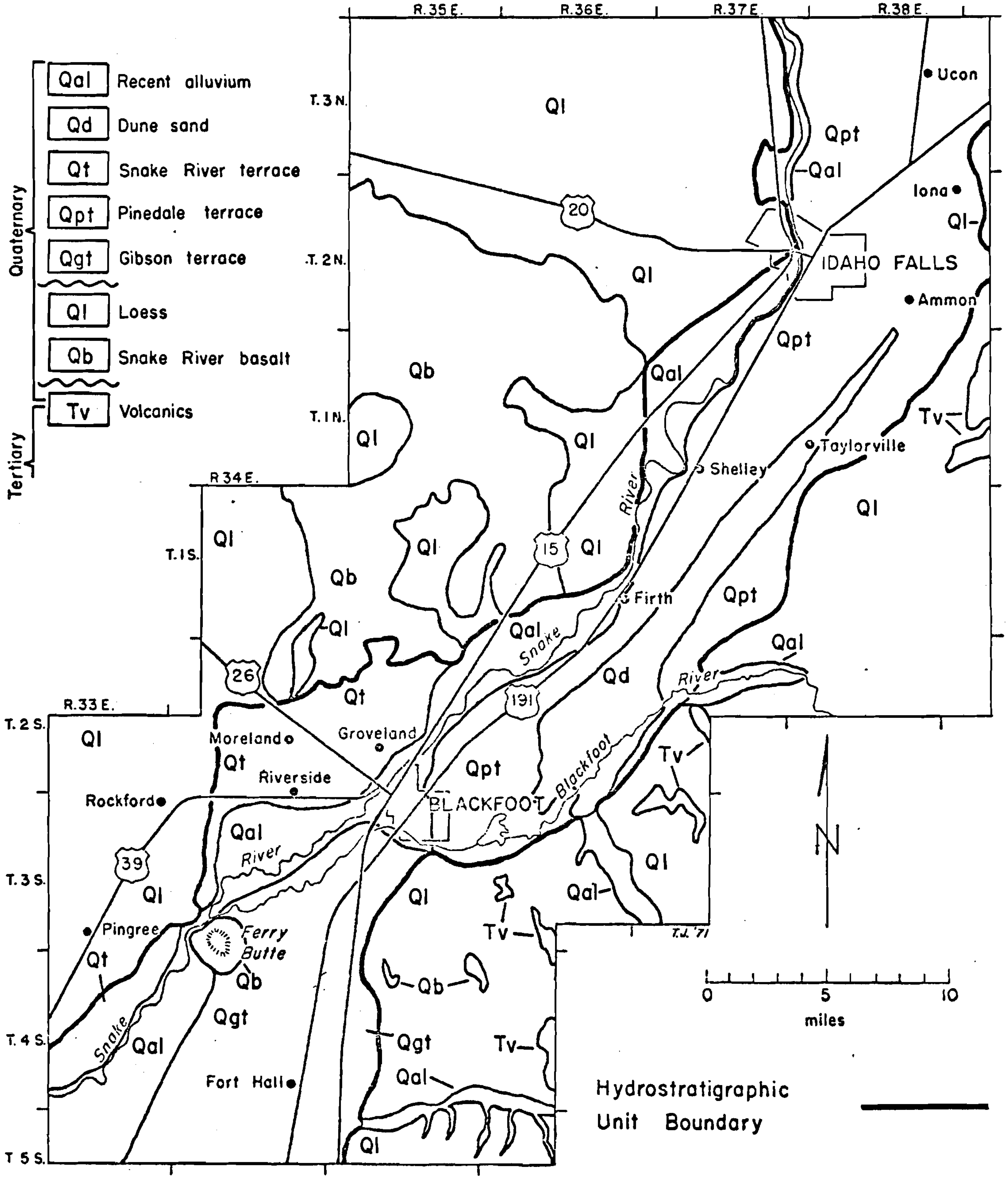


FIGURE II-8. Ground-water table and shallow flow system.

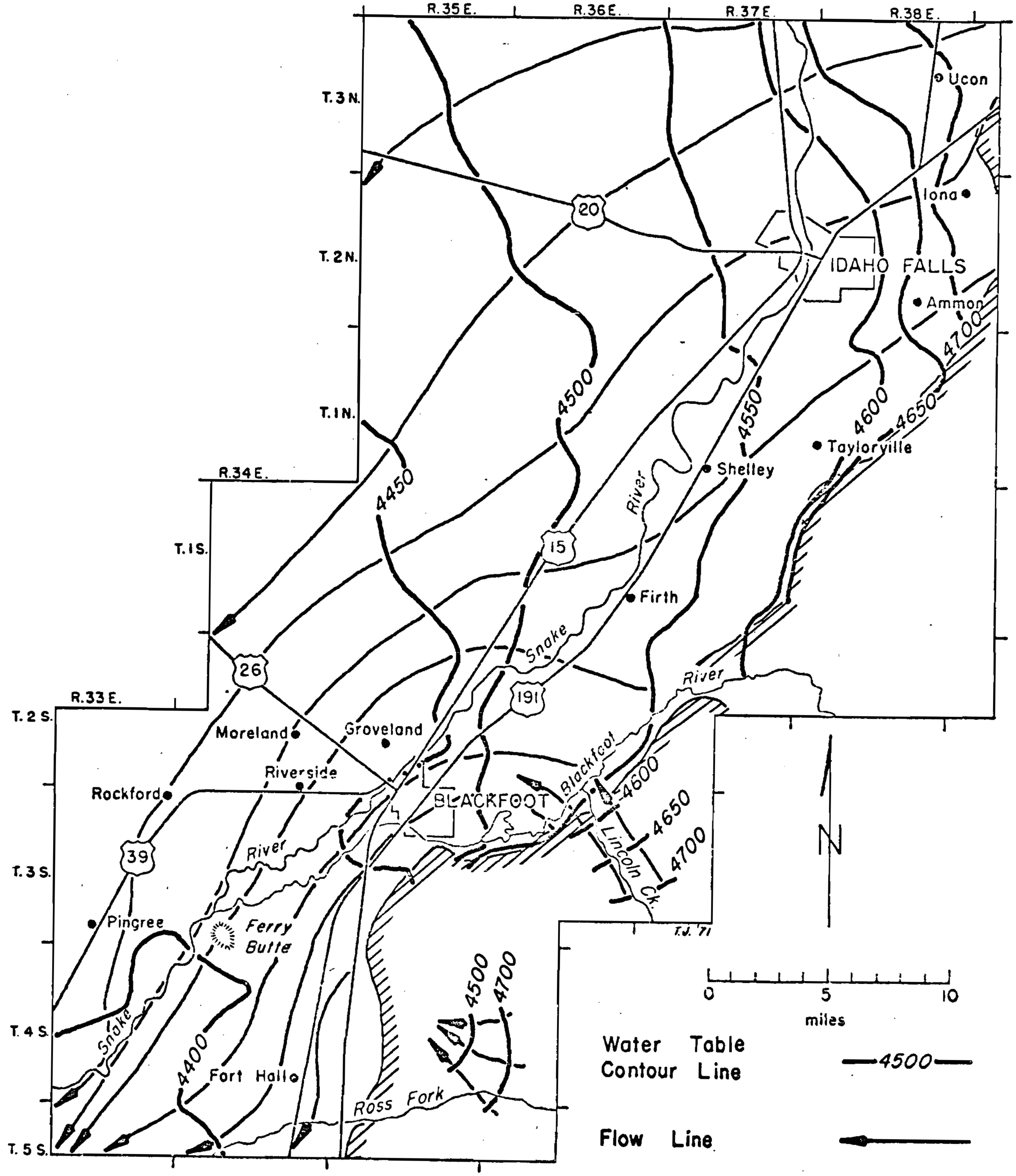


FIGURE II-9. Refined characterization of favorable waste-water disposal sites.

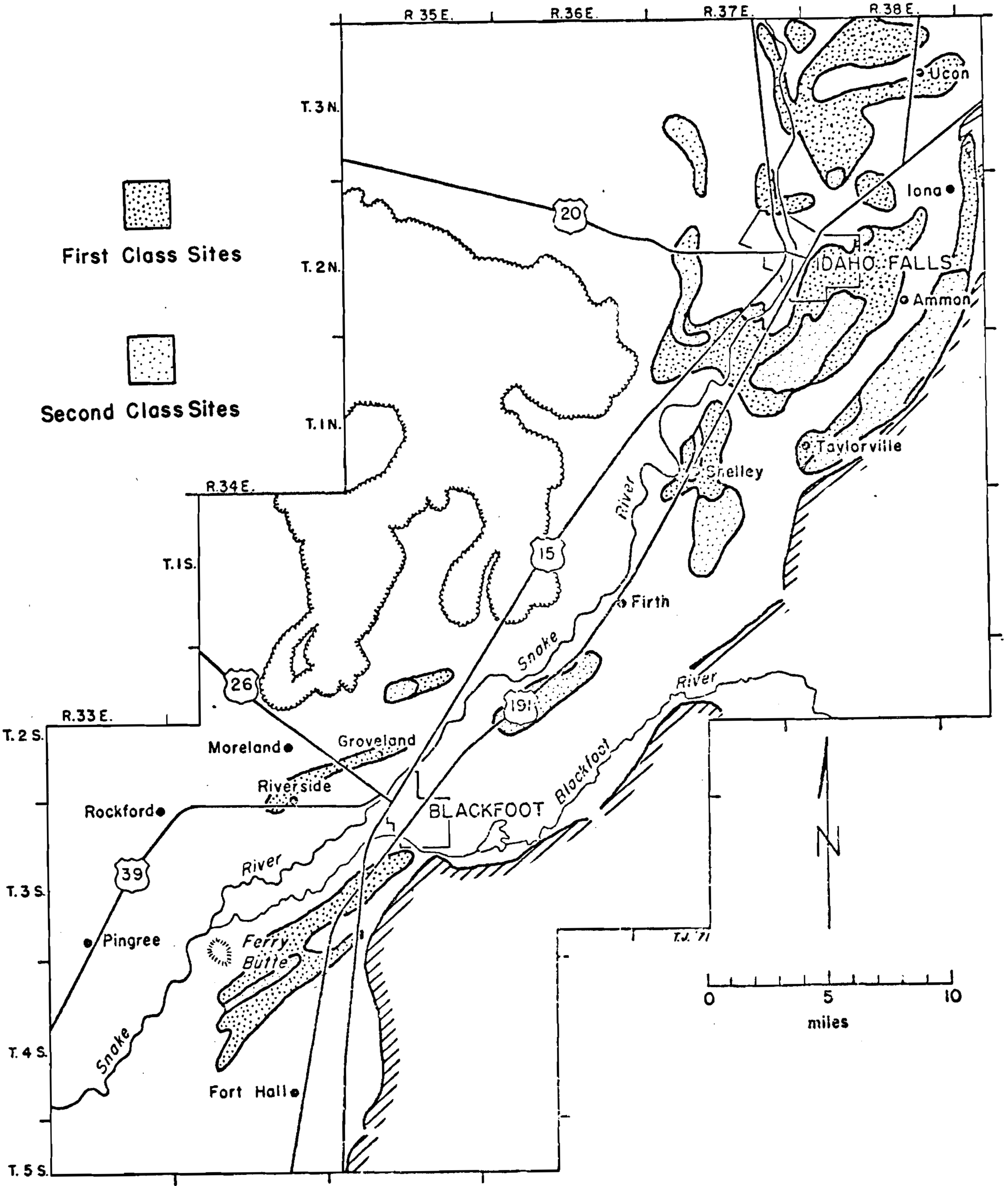
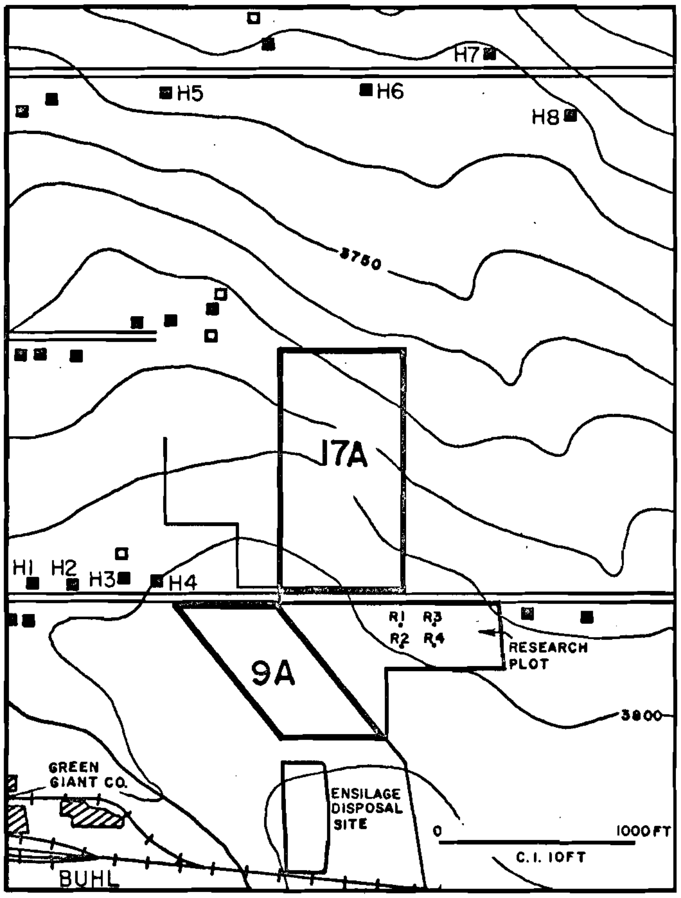
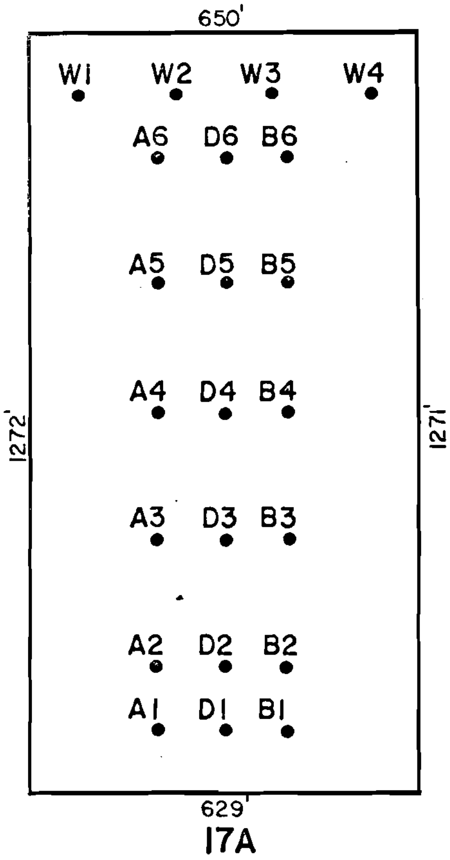
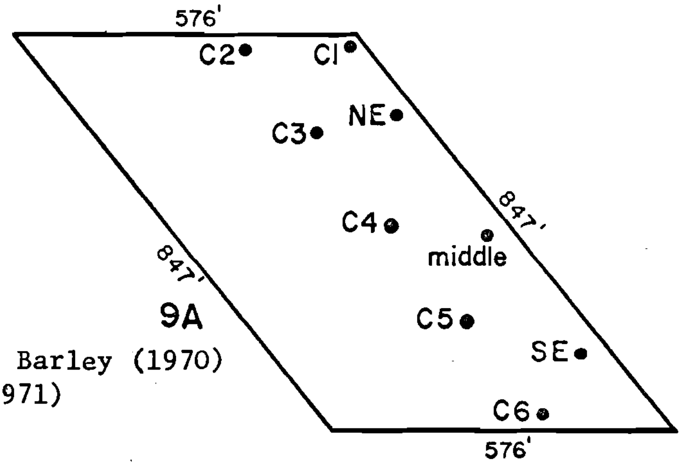


Figure III - 1 Topography and Field Locations with moisture extraction tube sites at sweet corn processing plant near Buhl, Idaho

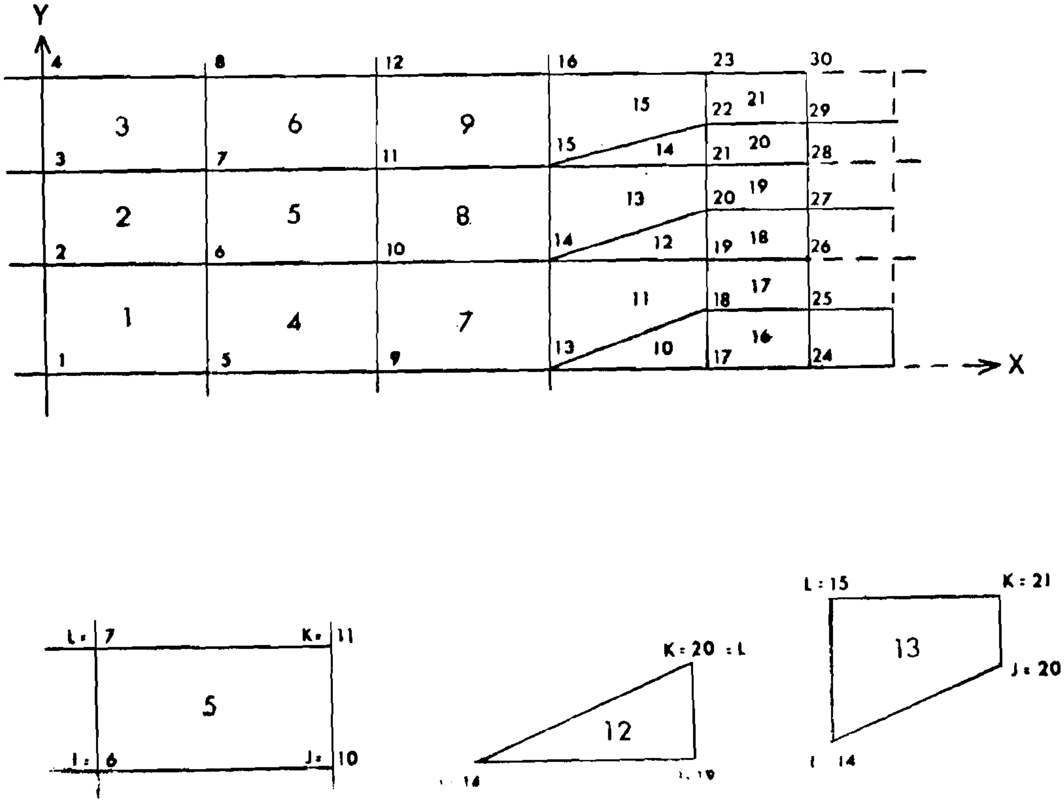






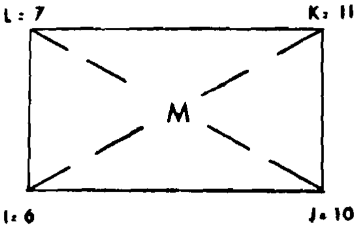
9A - Late cornfield (1969 and 1971) Early Barley (1970)
17A - Late cornfield 1970, Early Barley (1971)
NE -
SE - } Collection Tube Sites, 1969

A1.......A6 - Collection tube sites and neutron probe sites, 1970-1971
B1.......B6 - Collection tube sites and neutron probe sites, 1970-1971
C1.......C6 - Collection tube sites and neutron probe sites, 1971
D1.......D6 - Collection tube sites and neutron probe sites, 1971
R1.......R4 - Collection tube sites, 1971
H1.......H8 - Domestic well sample sites, 1969 and 1971



element 5 element 12 element 13

INPUT MESH NOTATION



Program division of Quadrilateral & placement of Node M

Figure V-1 - NOTATION FOR MESH AND INDIVIDUAL ELEMENTS

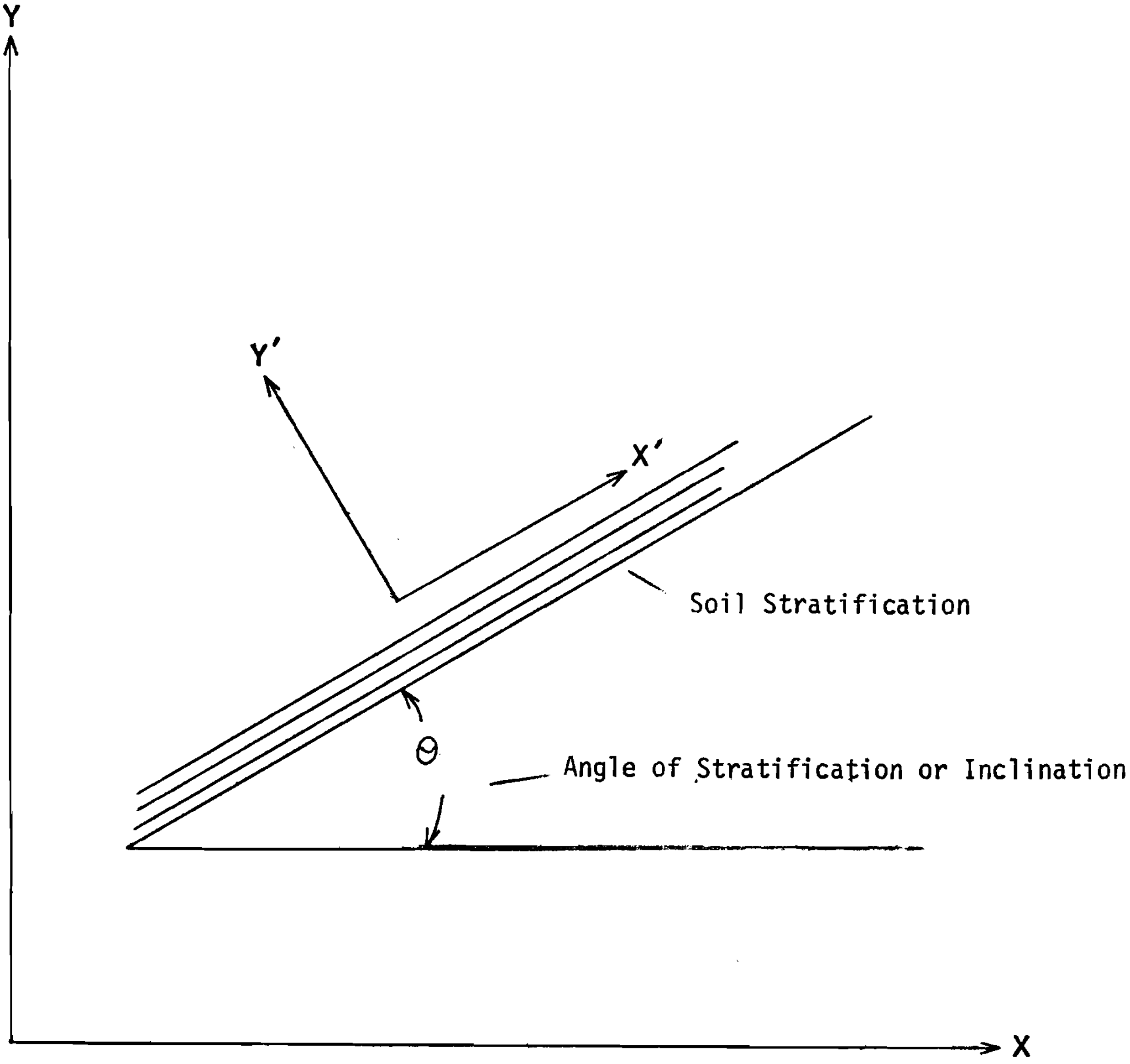


Figure V-2 - COORDINATE SYSTEM (X',Y') FOR ANISOTROPIC PERMEABILITY ORIENTATION OR INCLINATION OF UNITS AND REFERENCE COORDINATES (X,Y)

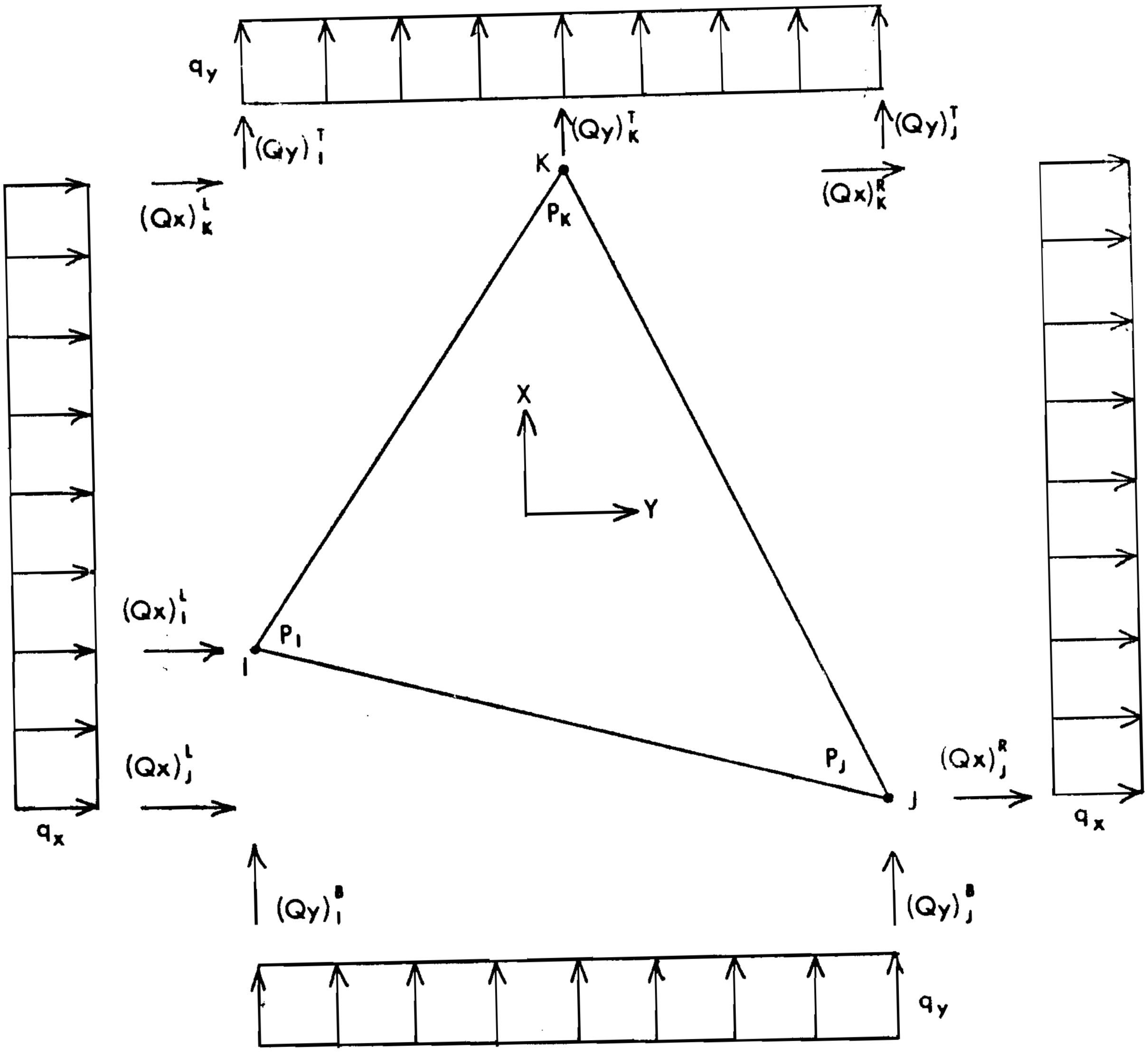


Figure V-3 - ELEMENT NODAL FLOWS

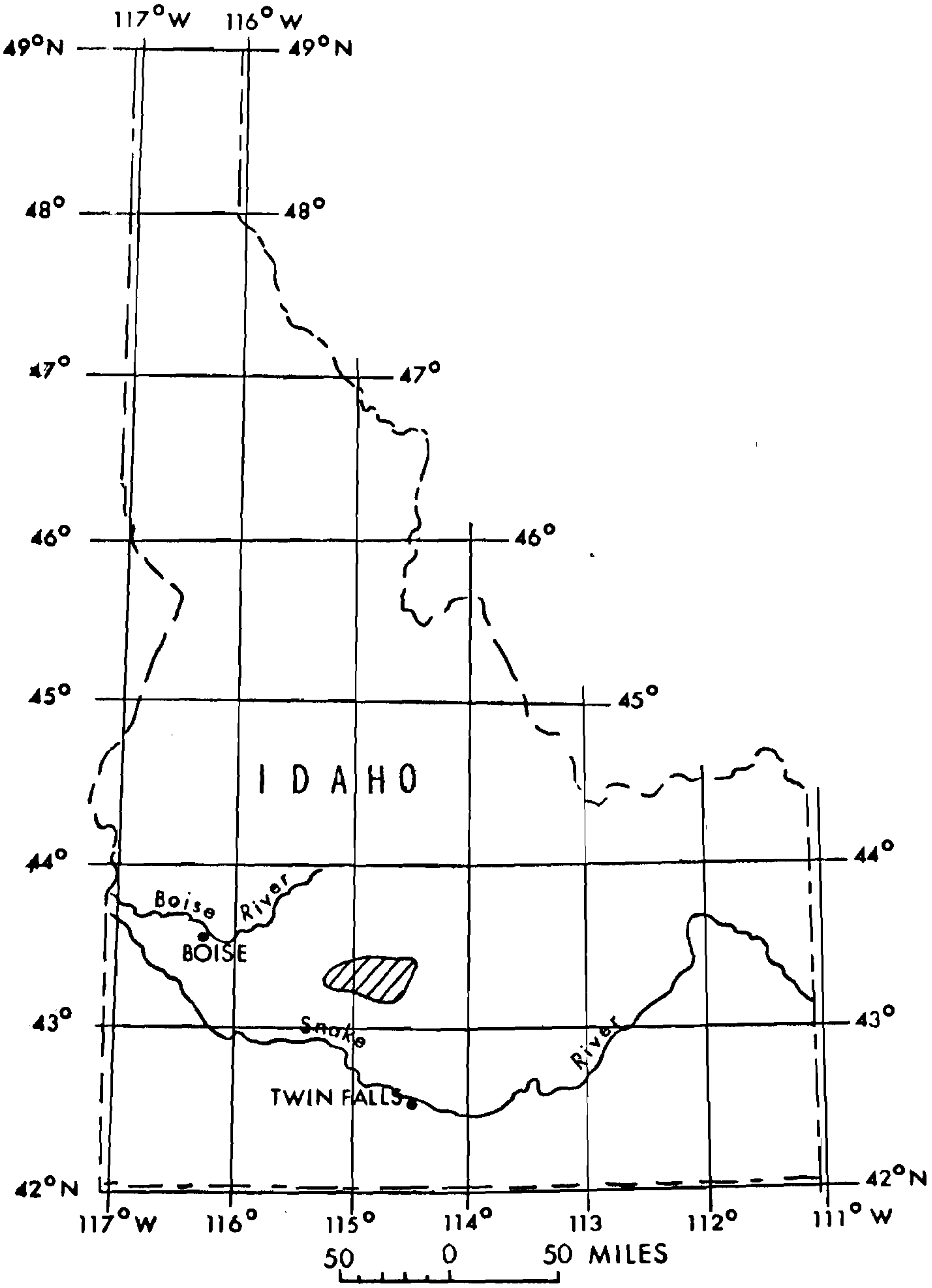


Figure V-4 - INDEX MAP SHOWING LOCATION OF CAMAS PRAIRIE