EFFECT OF A GRASS AND SOIL FILTER ON TUCSON URBAN RUNOFF: A PRELIMINARY EVALUATION

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Abstract. Storm runoff from the Tucson metropolitan area is unsuitable for most uses without processing. A lysimeter comprised of a grass and soil filter was constructed and is being evaluated as a water-quality treatment facility. The lysimeter is 200 feet long, 4 feet wide and 5 feet deep, and contains homogeneous calcareous loam covered by common grasses. Experimental apparatus was installed to divert less than a cubic foot per second of runoff from urbanized Arcadia Watershed. Runoff flows by gravity over the lysimeter, where surface inflow, surface outflow and subsurface outflow are measured and sampled. Four trials, each associated with a discrete runoff event, were conducted in the fall of 1971. Water samples were analyzed for inorganic chemical constituents, chemical oxygen demand (COD), coliforms, turbidity and sediment contents. Subsurface-outflow samples from initial trials were high in COD and total dissolved solids, representing soil flushing or leaching. Concentrations of inorganics reached a maximum value within a few hours of initial seepage, and then decreased. The peaking represents a salt build-up between trials. Concentrations of COD, coliforms, turbidity and sediment in subsurface-outflow samples decreased significantly during each trial. Surface-outflow samples had lower turbidity, COD, bacteria and sediment contents than surface-inflow samples. Turbidity, suspended and volatile solids, coliforms and COD in runoff samples may be reduced by grass and soil filtration. Increased grass development and soil settling work to produce a better quality effluent. Quantification of the lysimeter's effectiveness will be useful for urban watershed management.

INTRODUCTION

Water in the semiarid and arid environment is a limited resource which must be managed efficiently and economically. Urban water problems in such an environment are unique in that the watershed changes rapidly in time with urbanization. Hydrologic effects of urban growth include increase in runoff volume and flood hazard, degradation of streamflow quality and increase in demand for water. Many southwestern cities are growing at rates that make these hydrologic effects significant. Increases in construction of flood- detention and routing structures, water and waste-water treatment plants, and fire-protection and water-conveyance units are apparent in recent years.

The University of Arizona has undertaken an interdisciplinary Urban Hydrology Study with the support of a grant from the Office of Water Resources Research, U. S. Department of the Interior. Multipurpose objectives of this research are the following:

1) To collect and interpret hydrologic data on the Tucson, Arizona, metropolitan region.
2) To develop management procedures for urban runoff in arid lands.
3) To apply a systems approach with interdisciplinary objectives to the problems defined.
4) And to aid in training students as hydrologists.

Through this study, a management procedure which reduces summer flood peaks by diverting channel flow following removal of sediment to surface ponds and/or recharge wells is being considered. Initial benefits will be flood control and resulting decrease in economic loss function. Surface ponds and detention areas could be used simply for water detention and subsequent release to stream channels or to recharge structures, or to be developed as recreational areas. There are many benefits here--benefits of flood control, of recharge and of recreation. Recharging could be achieved by wells, shafts, pits or channels. Recreation could include water-related activities, or simply open spaces with or without ponds. Reclaimed flood water could supplement irrigation water for a park. Use of flood water for recharge of recreation would reduce demands for limited ground-water or costly surface-water reservoirs. The total management scheme would be under the constraints of total costs, nature of predictability of streamflow quality and quantity, political wisdom and legal factors. Such a plan requires comprehensive analysis.

Water quality is an important consideration under any management procedure for both recharge and recreation. Recharge water should be free of algae, sediment, turbidity, organic material, bacteria and dissolved gases to be efficient. It should be of a caliber which will not degrade the water stored in the aquifer if ground-water quality is to be maintained. Ponded water has quality restrictions depending on intended use. Water for public consumption, swimming, fishing and types of irrigation must meet legal standards.

Runoff in the Tucson metropolitan area is typically high in fecal and total coliforms, organic matter, sediment and turbidity, while low in total dissolved solids and most inorganic constituents. It may at times have a high temperature and contain varying amounts of pesticides and phenols. Methods of water-quality treatment, in a spirit consistent with urban arid hydrology, need evaluation.

This paper presents a preliminary analysis of the effectiveness of a grass and soil filter as a water-quality treatment for Tucson urban runoff. Quantification of this process's effectiveness will be useful for urban watershed management.

METHODS

Experimental Facilities

A grass and soil filter water-treatment pilot plant (Figure 1) was constructed by the Water Resources Research Center in the summer of 1971 on Tucson

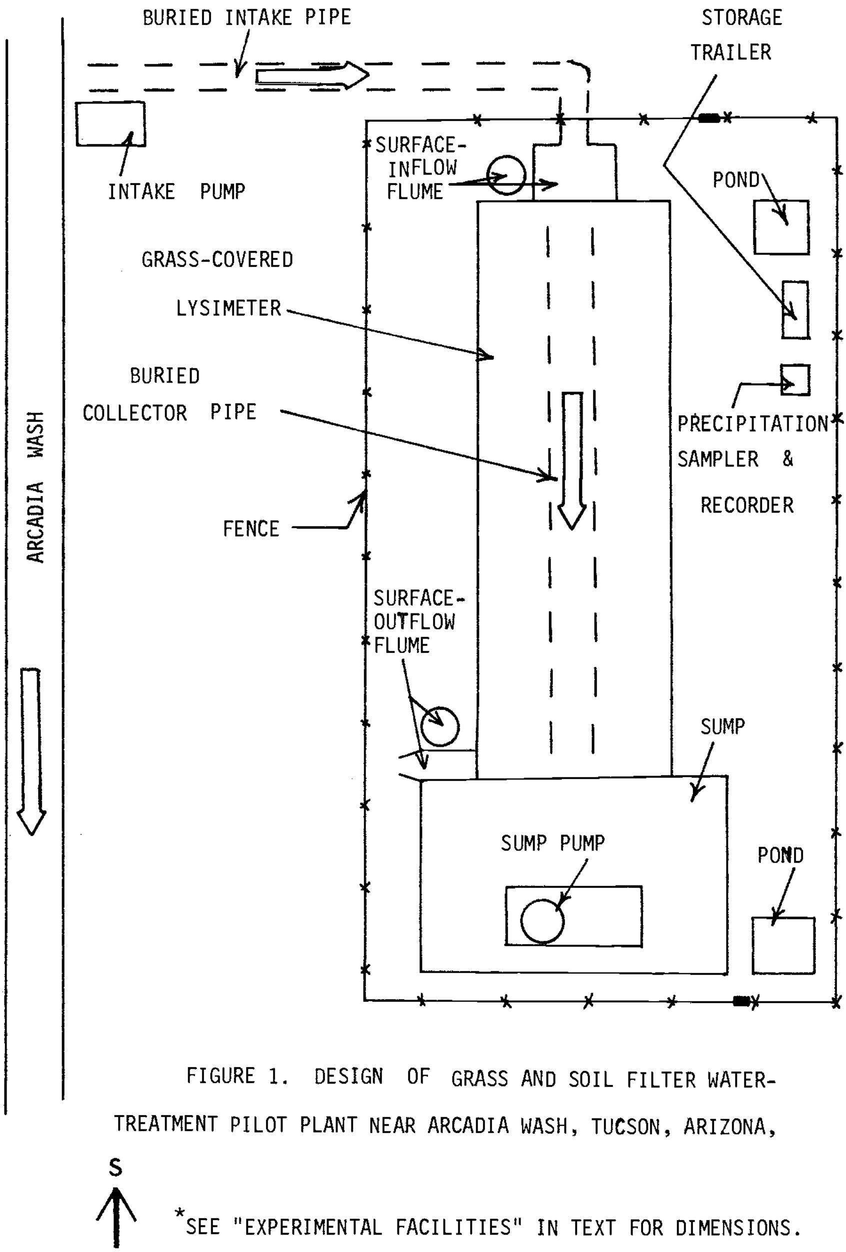

FIGURE 1. DESIGN OF GRASS AND SOIL FILTER WATER-TREATMENT PILOT PLANT NEAR ARCADIA WASH, TUCSON, ARIZONA,

*SEE "EXPERIMENTAL FACILITIES" IN TEXT FOR DIMENSIONS.

Medical Center property in northeast Tucson, 200 feet west of ephemeral Arcadia Wash (Figure 2). The wash drains a 6-square mile urbanized basin. This site was selected because of watershed properties and potential recreational development. The pilot plant is a 200-foot long, 4-foot wide and 5-foot deep lysimeter consisting of native calcareous loam and covered with common rye grass in fall and winter and Bermuda grass in spring and summer. A one-percent slope is maintained on the top and bottom of the filter. Lysimeter sides and base, below the ground surface, are lined with sprayed asphalt and two layers of 10mm-thick black plastic sheeting, installed in strips 16 feet wide and 100 feet long. The lined base is gravel-packed around a 6-inch diameter saw-slotted polyvinyl chloride (PVC) pipeline to accept and transport seepage water to a 5-foot long, 3-foot wide and 10-foot deep concrete block sump. Walls of the filter, above the ground surface, consist of two tiers of 8 x 8 x 16 inch block, covered with plastic, chicken wire and plaster. Sump blocks and wall plaster are painted with colorundum sealer to prevent seepage.

A gasoline-powered centrifugal pump with a capacity less than a cubic foot per second is installed on the west bank of the wash to divert storm runoff through a 3-inch diameter PVC pipeline. The pipeline ends at a 3-inch Parshall flume at the surface inlet. Surface outflow from the filter is measured by a one-foot H flume at the surface outlet. Both flumes have continuous stage recorders and staff gages. Subsurface outflow from the filter is collected in a sump and measured by a staff gage and by pumping to calibrated barrels by means of a gasoline-powered submersible pump. A plastic non-recording raingage, plastic funnels for precipitation sampling, and an equipment-storage trailer are impounded by the 230-foot long, 50-foot wide and 6-foot high long chain linked fence which surrounds the pilot plant.

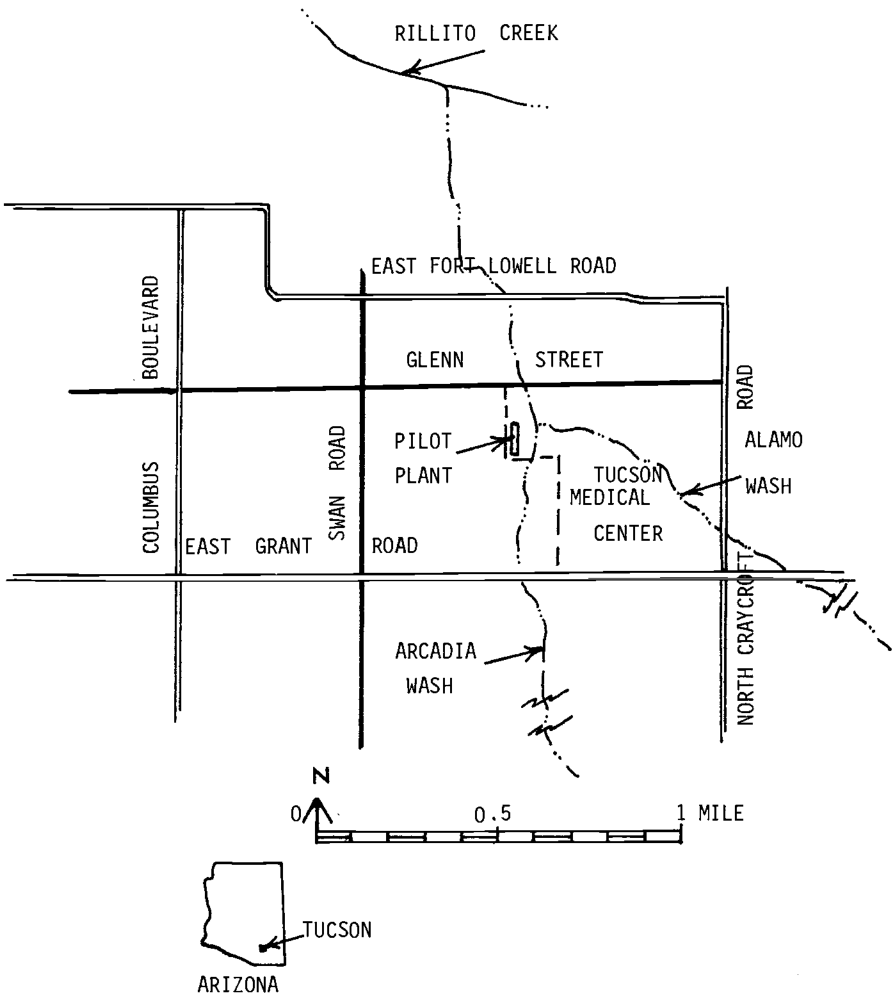

FIGURE 2. LOCATION OF GRASS AND SOIL FILTER WATER-TREATMENT PILOT PLANT IN NORTHEAST TUCSON, ARIZONA

Data Collection

A runoff producing storm, sufficient to supply the intake pump with water, is called a trial. Four trials, each associated with a discrete runoff event, summarized in Table 1, occurred in the fall of 1971. The procedure was to pump water to the lysimeter, noting time and flume stage. Water samples and temperatures were taken from the wash, and surface- inflow and outflow flumes, and seepage discharge pipe. Subsurface outflow was measured with buckets and calibrated barrels. Precipitation was measured for all trials, and sampled for the last two trials. Grass-filtered sediment was measured for each trial.

TABLE 1: Summary of Fall 1971 Trials at Grass and Soil Filter Water-Treatment Pilot Plant

	TRIAL 1	TRIAL 2	TRIAL 3	TRIAL 4
Date of flow event	Oct. 17	Nov.15-16	Dec.7-8	Dec.13-14
Surface-inflow volume (gal)	18,350	88,000	16,600	6,900
Surface-outflow volume (gal)	16,150	77,200	14,750	6,200
(percent of inflow)	88	88	89	90
Subsurface-outflow volume and abstractions (gal)	2,200	10,800	1,600	700
(percent of inflow)	12	12	11	10
Duration of surface application (min)	303	1,770	1,125	195
(hrs)	5	30	19	3
Duration of seepage (min)	1,710	20,205	7,965	13,170
(hrs)	29	337	133	220
Grass-filtered sediment (cu ft)	20.5	30.0	3.7	2.8
Precipitation at plant (in)	0.9	0.8	0.8	0.3

Data Analysis

Discharge data were calculated to within about 10 percent with the help of the Center's Wang desk computer to determine mass flow. Water samples were refrigerated to inhibit bacterial activity. Samples were selectively analyzed for chemical oxygen demand (COD), total and fecal coliform, turbidity, and volatile and suspended solids by the University of Arizona Sanitary Engineering Laboratory. Selective samples were analyzed for inorganic mineral constituents by the University's Soil and Water Testing Laboratory.

Various time series were plotted for biological and chemical data using dimensionless, arithmetic, semilogarithmic and logarithmic scales.

RESULTS

Fourteen arithmetic and semilogarithmic graphs were used to convey information concerning turbidity, suspended and volatile solids, total and fecal coliforms, COD and total dissolved solids (TDS) for surface- inflow and outflow, and subsurface outflow samples, see Figures 3 to 16.

Turbidity graphs, Figures 3 and 4, indicate that grass and soil filtration, after a few hours, reduce turbidity into the range of precipitation water samples. This is virtually complete turbidity removal. As the grass developed, and the soil settled, treated water decreased in turbidity: that is, turbidity values were lowest for the later trials.

Suspended solids, Figures 5 and 6, similarly reduced in concentration when runoff ran through the plant. Soil filtering was more effective than grass filtering. Most of the soil-filtered samples had suspended-solid concentrations in the range of precipitation samples. Again, suspended solids decreased with grass development and soil settling.

Coliforms, Figures 7 to 10, generally decreased with succeeding trials, but may increase in the early part of any trial. Total and fecal coliforms in seepage samples, Figures 8 and 10, generally show a decrease in time

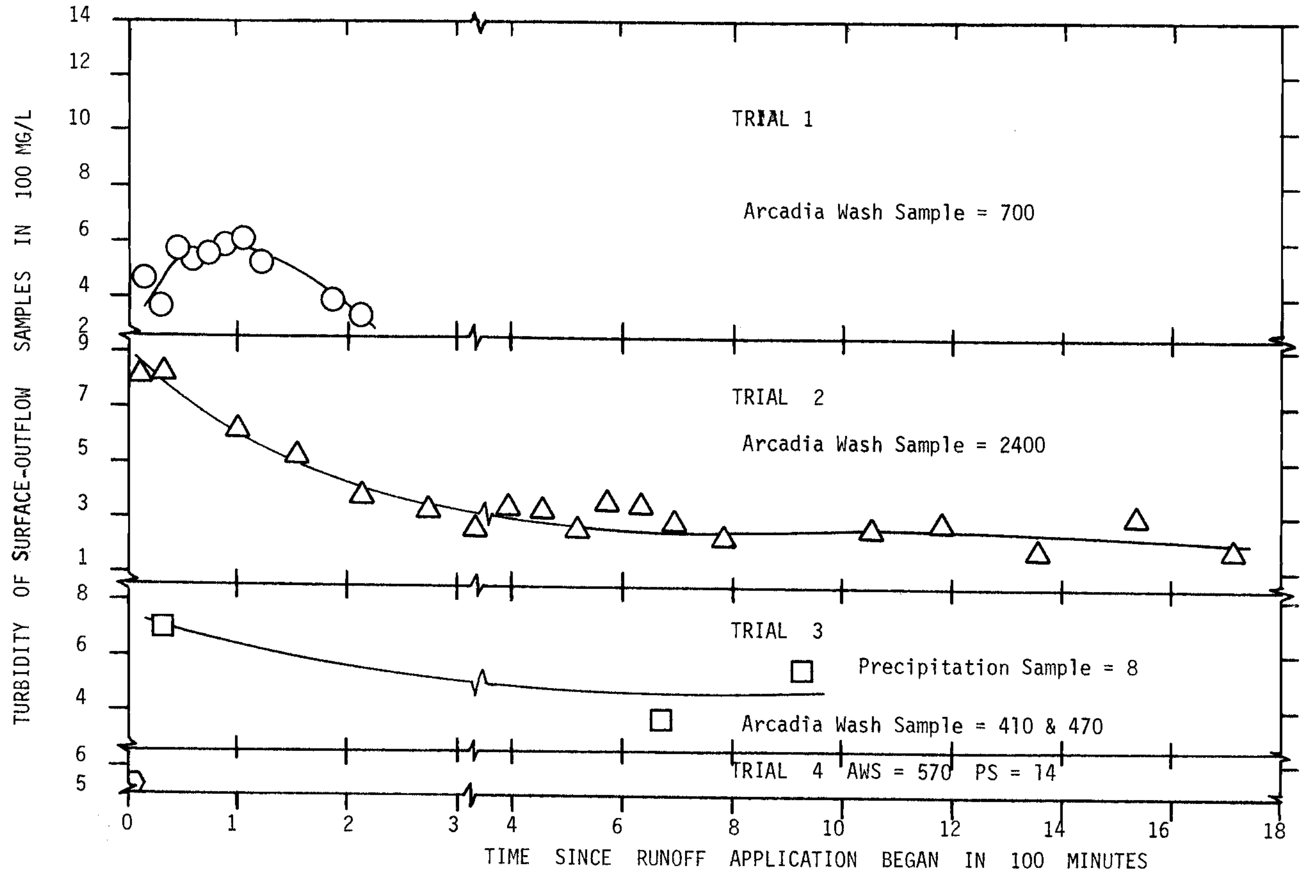

FIGURE 3. TURBIDITY SERIES OF SURFACE-OUTFLOW SAMPLES

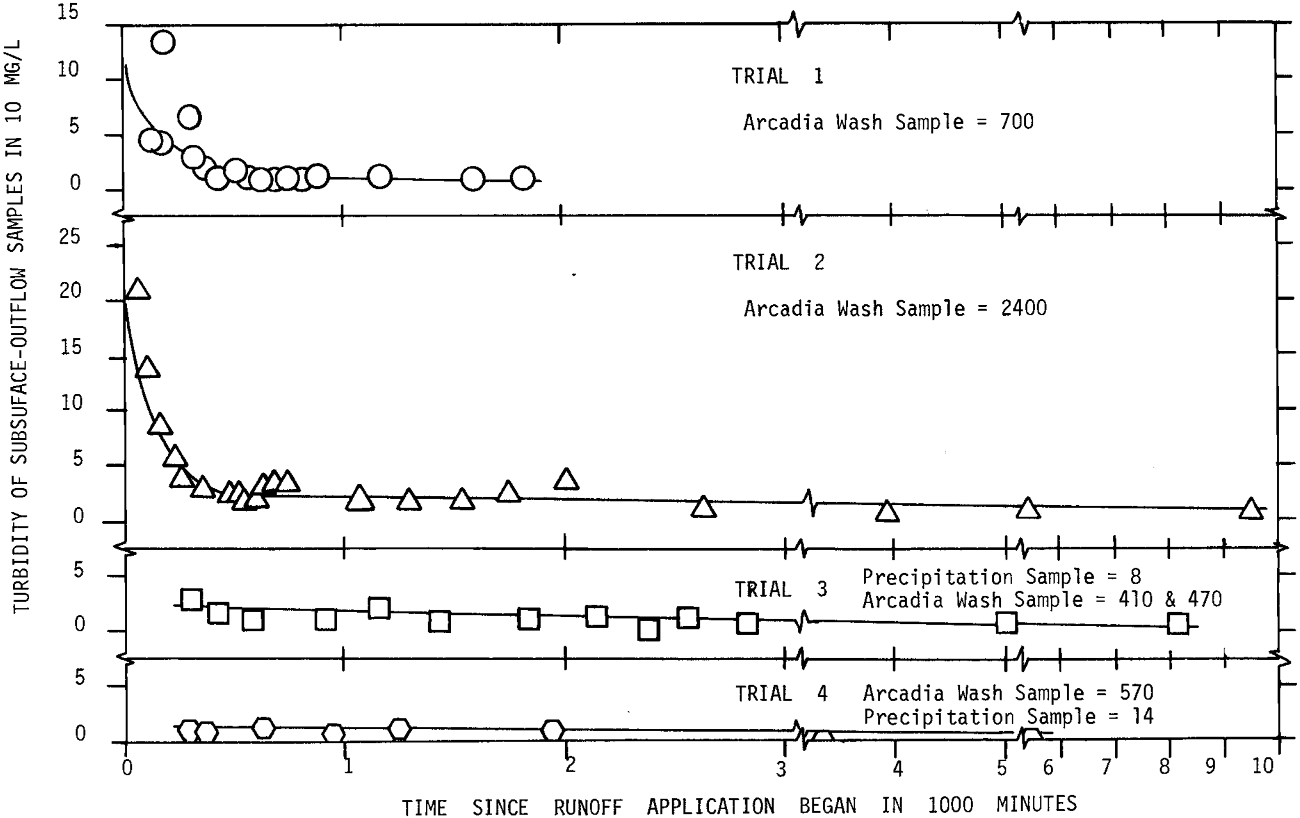

FIGURE 4. TURBIDITY SERIES OF SUBSURFACE-OUTFLOW SAMPLES

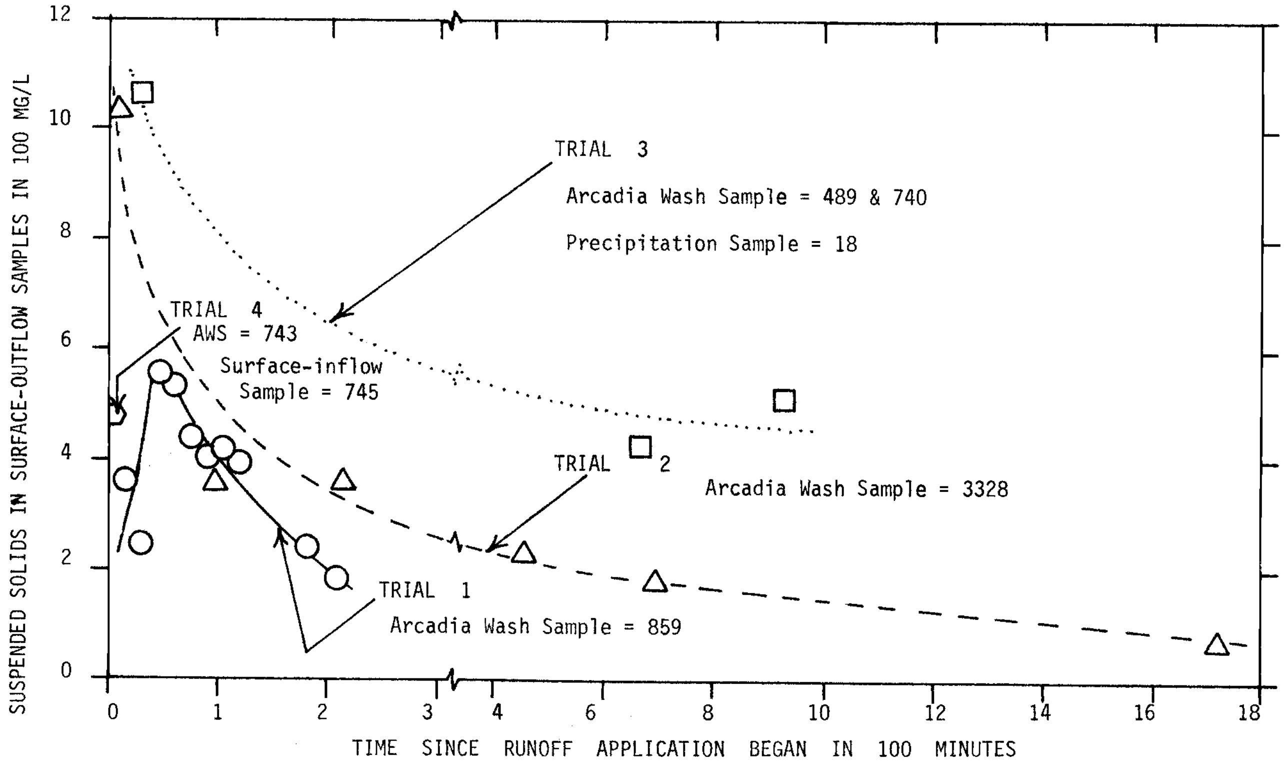

FIGURE 5. SUSPENDED-SOLIDS SERIES IN SURFACE-OUTFLOW SAMPLES

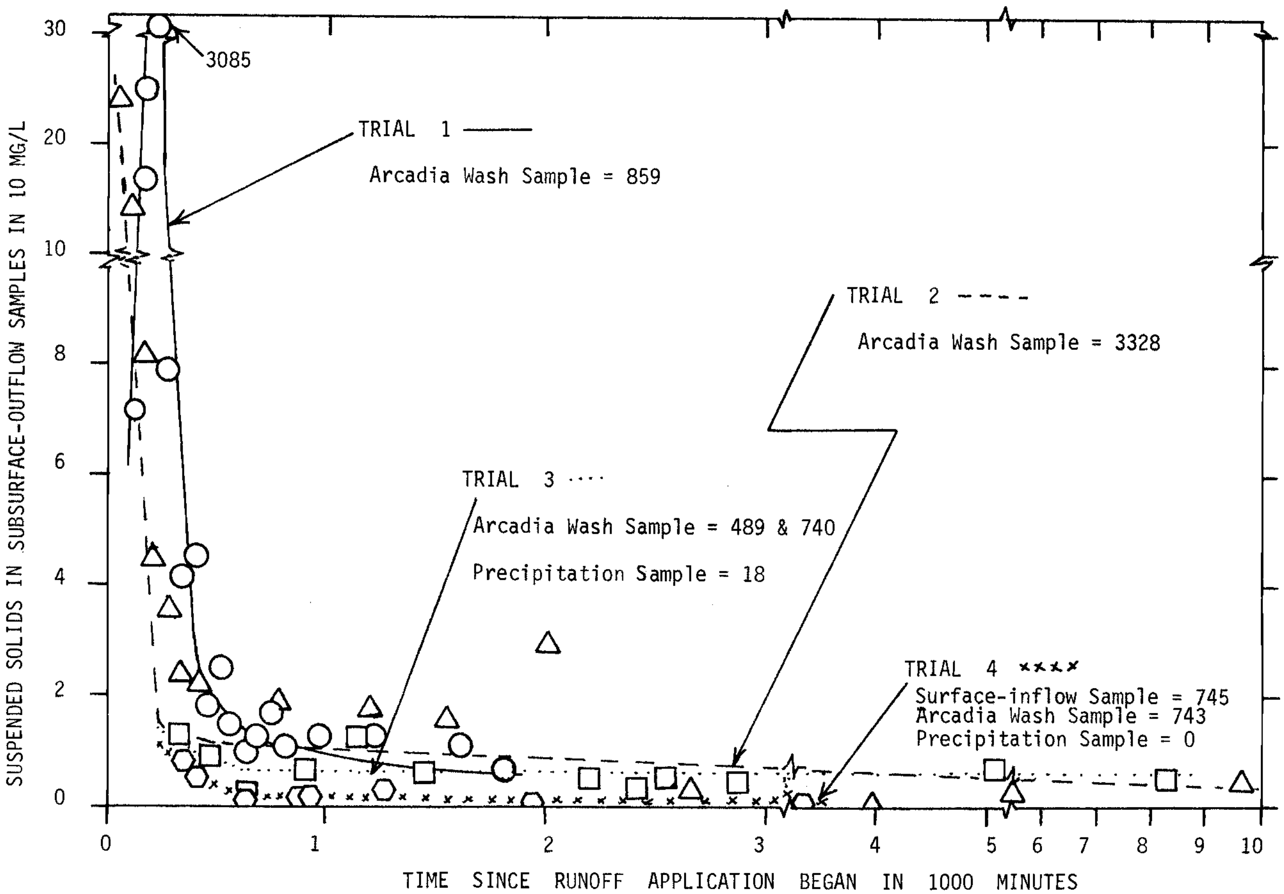

FIGURE 6. SUSPENDED-SOLIDS SERIES IN SUBSURFACE-OUTFLOW SAMPLES

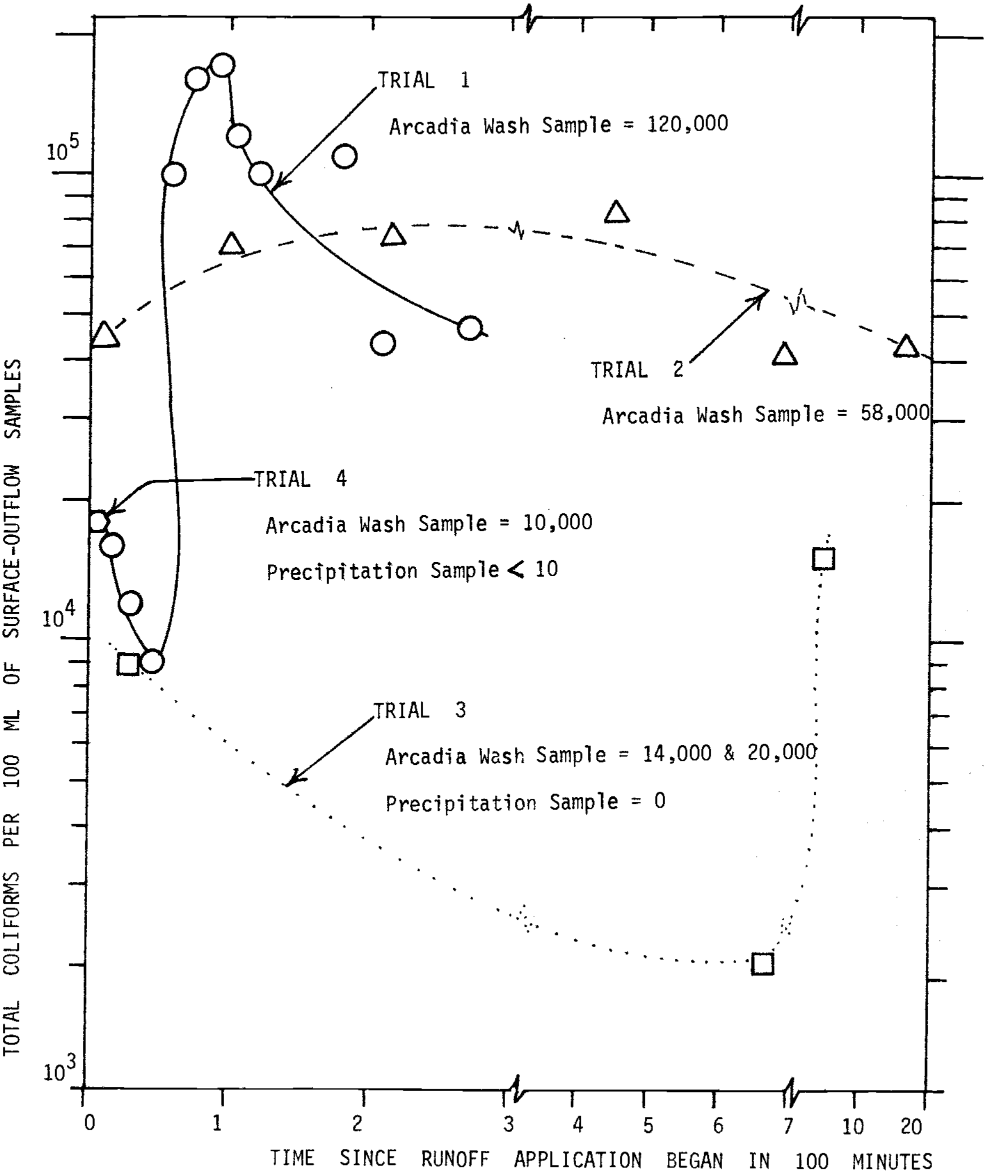

FIGURE 7. TOTAL-COLIFORM SERIES OF SURFACE-OUTFLOW SAMPLES

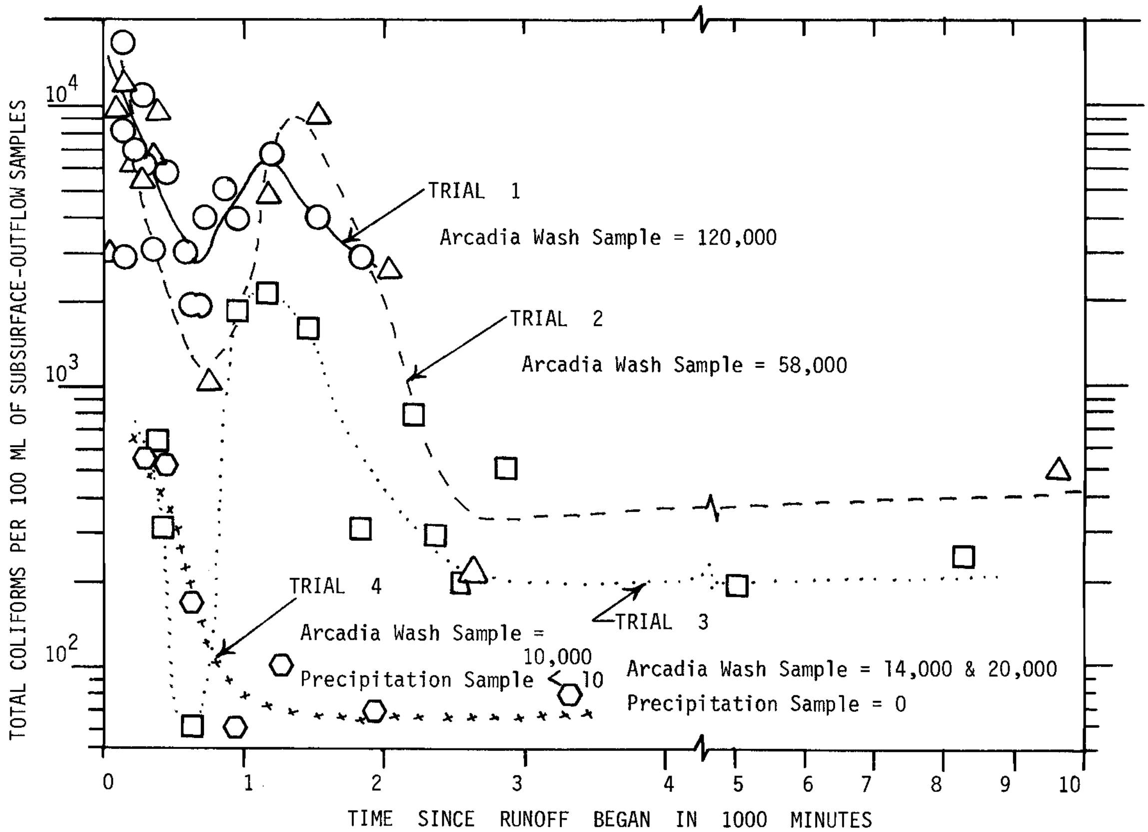

FIGURE 8. TOTAL-COLIFORMS SERIES OF SUBSURFACE-OUTFLOW SAMPLES

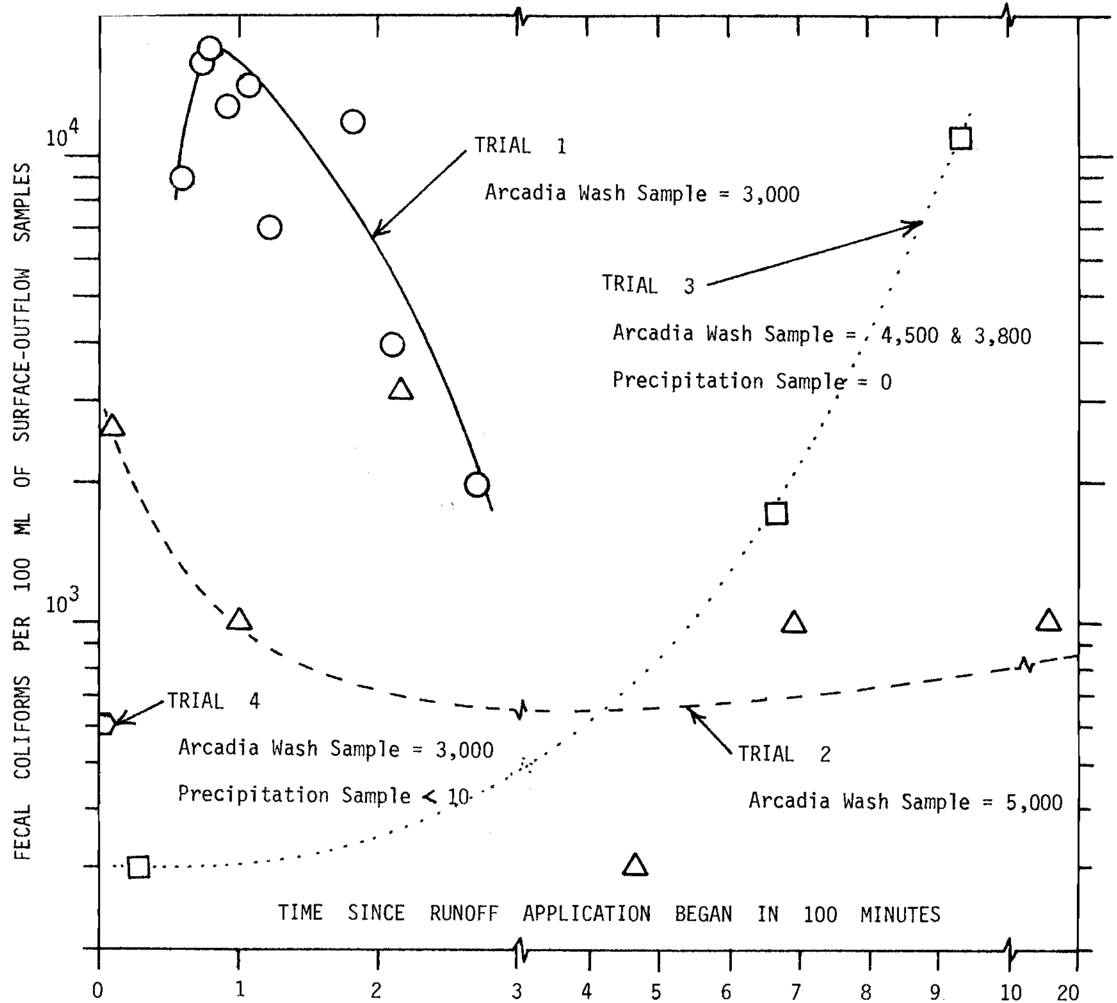

FIGURE 9. FECAL-COLIFORMS SERIES OF SURFACE-OUTFLOW SAMPLES

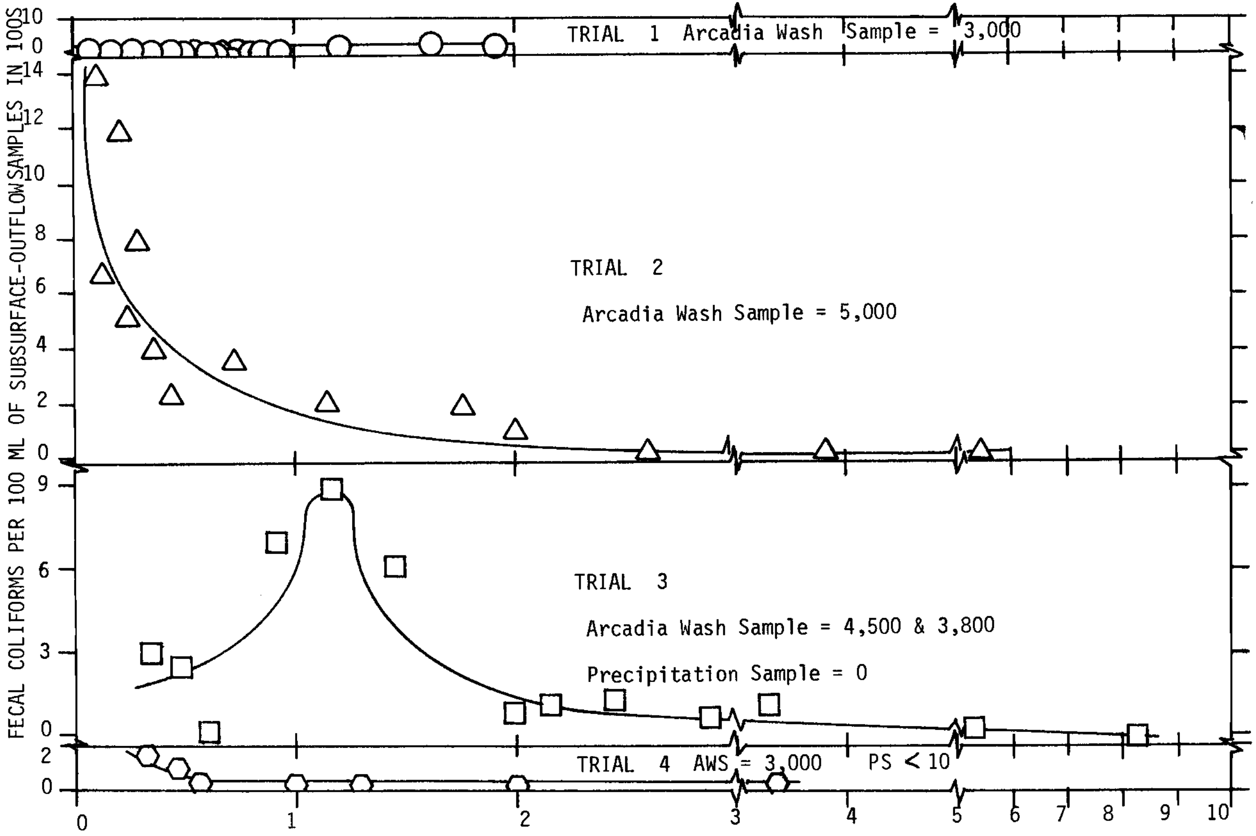

FIGURE 10. FECAL-COLIFORMS SERIES OF SUBSURFACE-OUTFLOW SAMPLES

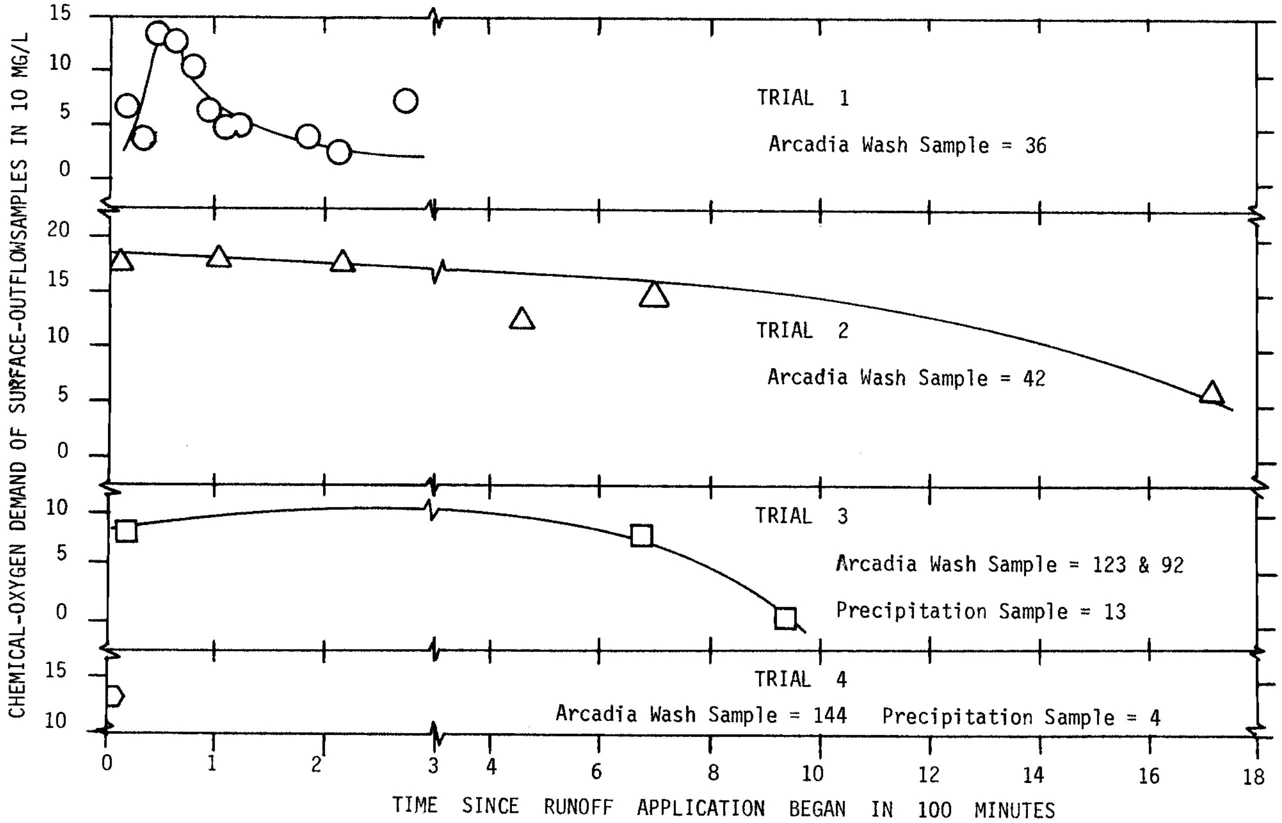

FIGURE 11. CHEMICAL-OXYGEN DEMAND SERIES OF SURFACE-OUTFLOW SAMPLES

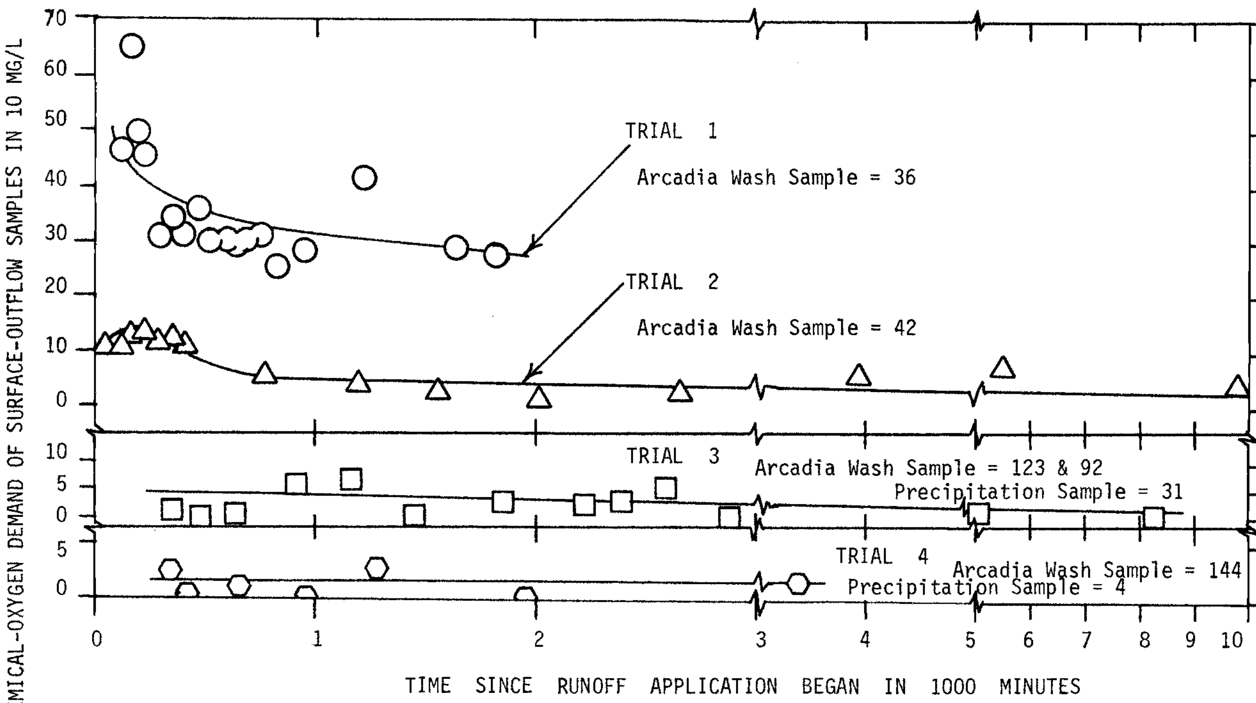

FIGURE 12. CHEMICAL-OXYGEN-DEMAND SERIES OF SUBSURFACE-OUTFLOW SAMPLES

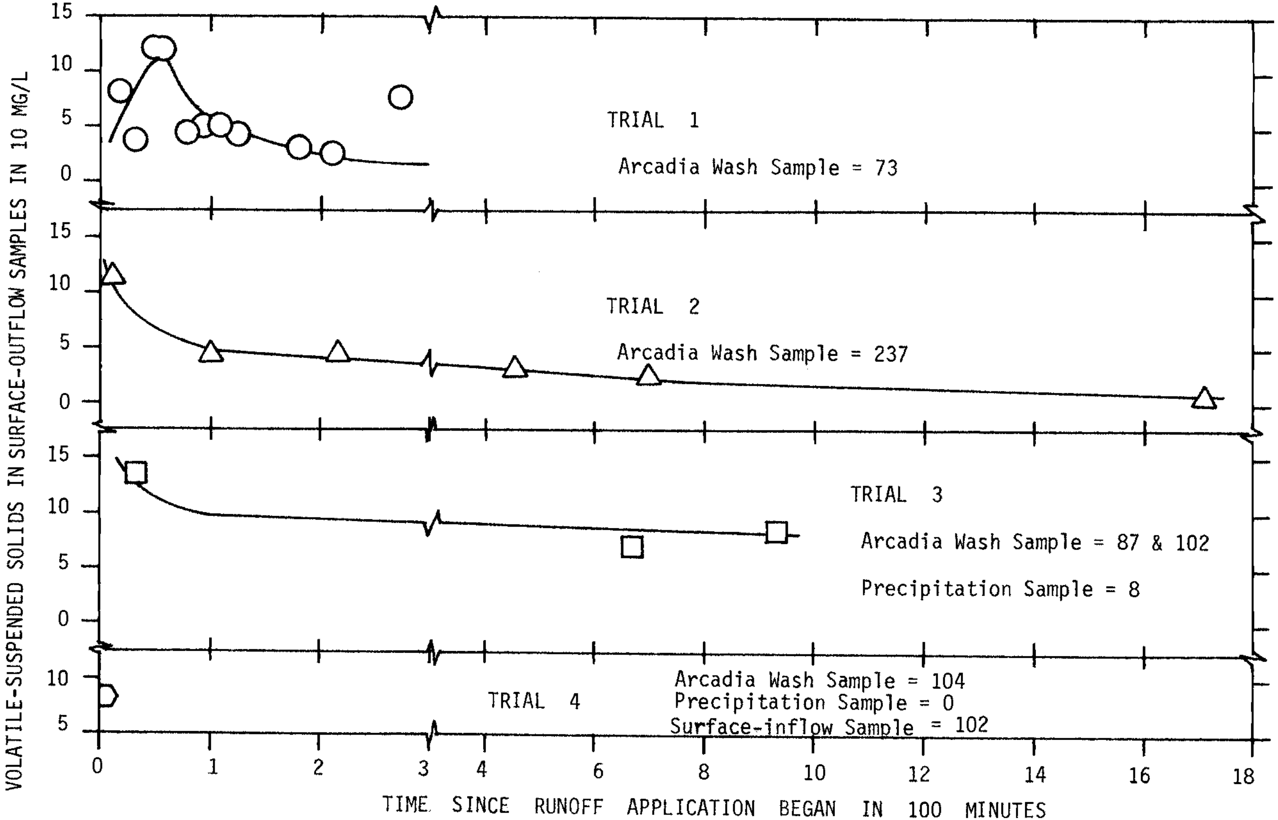

FIGURE 13. VOLATILE-SUSPENDED-SOLIDS SERIES OF SURFACE-OUTFLOW SAMPLES

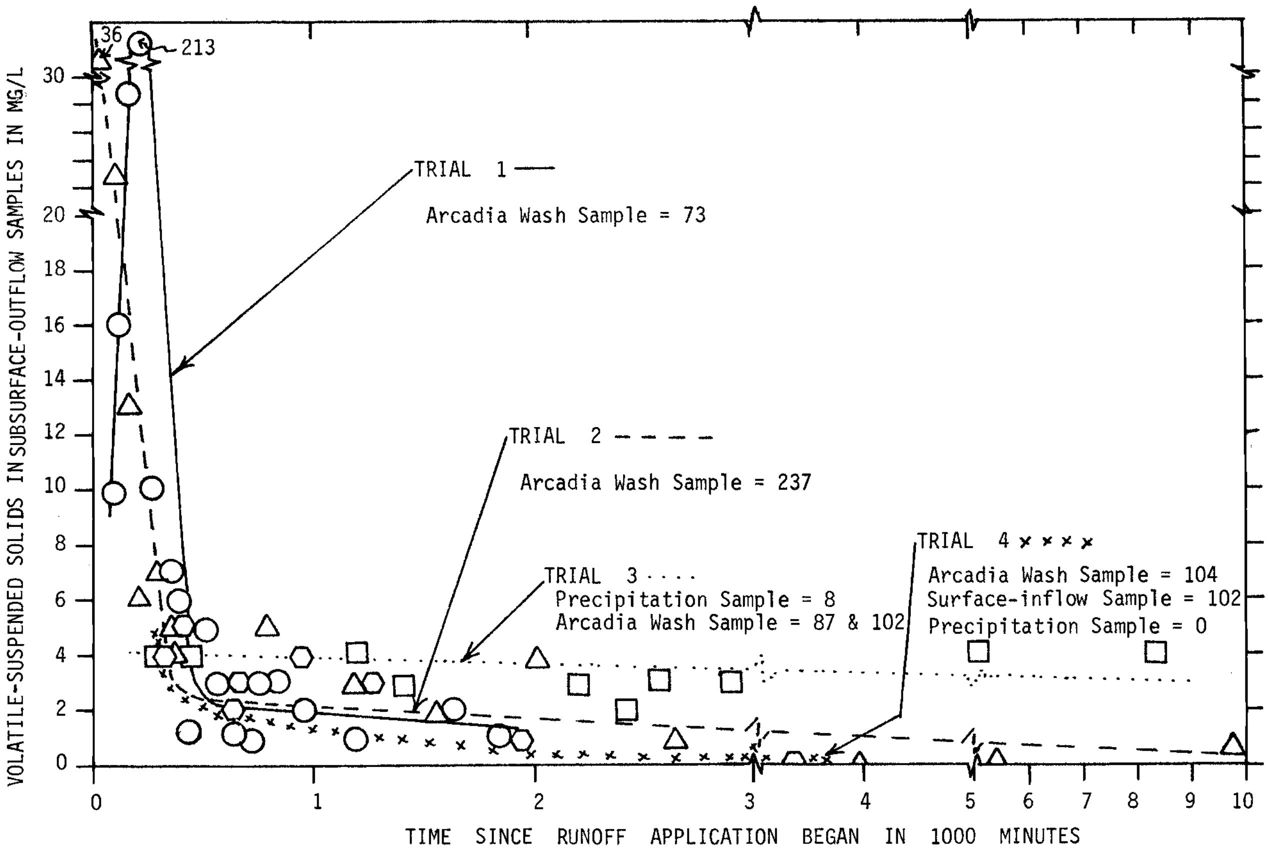

FIGURE 14. VOLATILE-SUSPENDED-SOLIDS SERIES OF SUBSURFACE-OUTFLOW SAMPLES

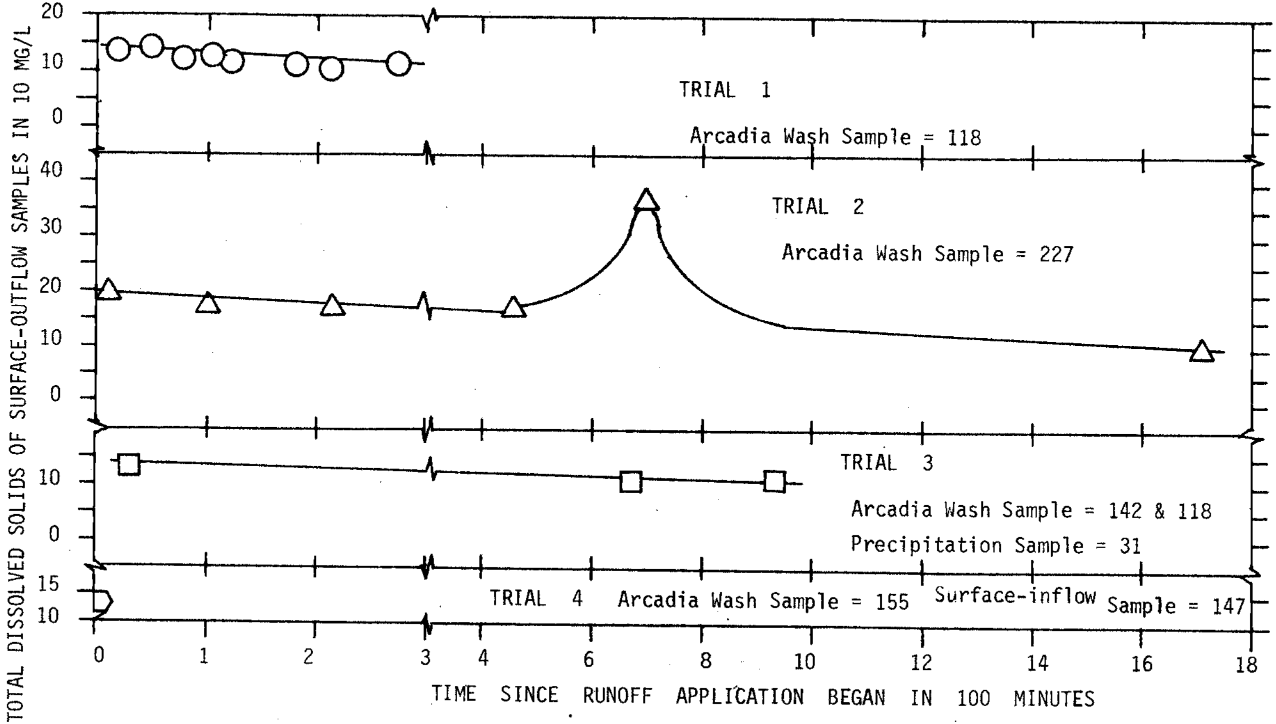

FIGURE 15. TOTAL-DISSOLVED-SOLIDS SERIES OF SURFACE-OUTFLOW SAMPLES

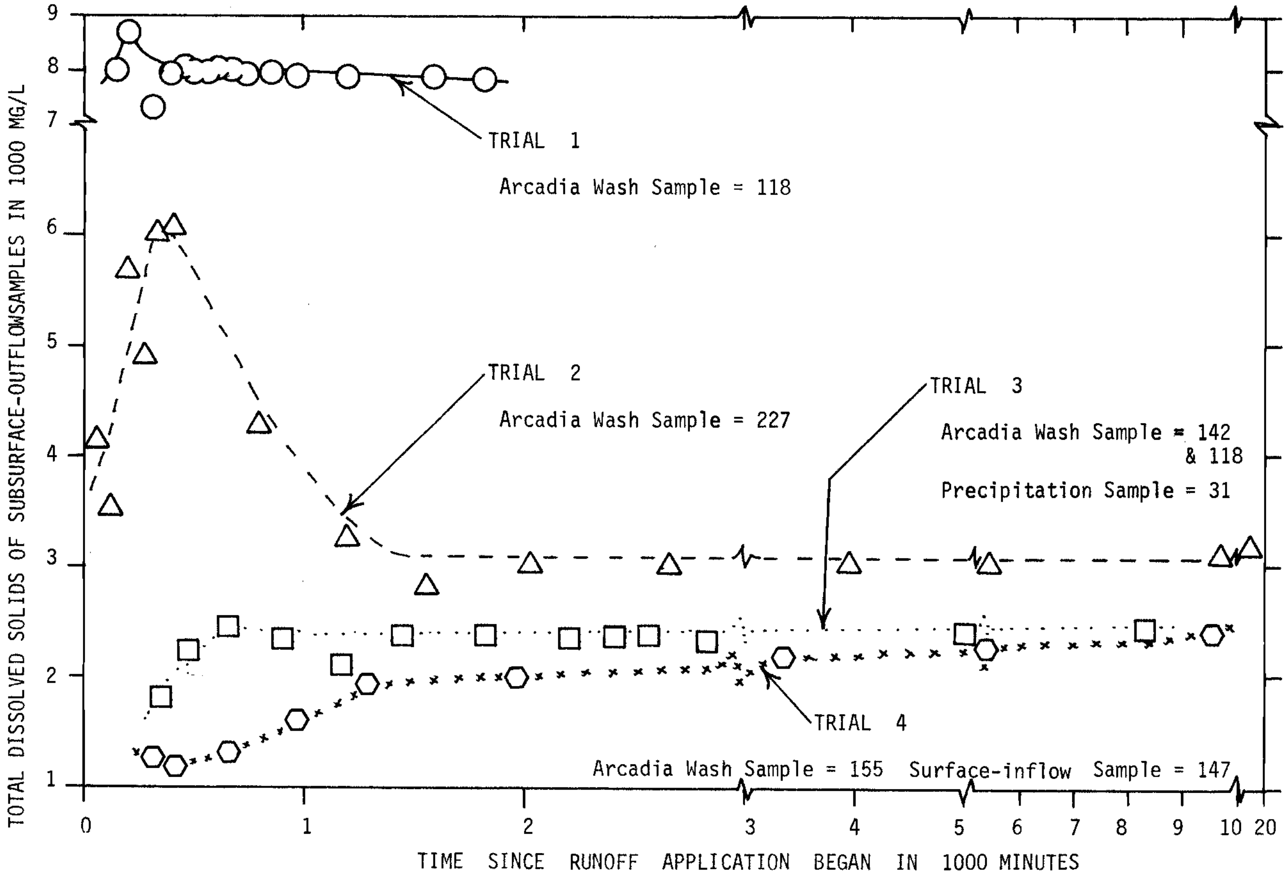

FIGURE 16. TOTAL-DISSOLVED-SOLIDS SERIES OF SUBSURFACE-OUTFLOW SAMPLES

with each trial and from early to later trials. Bacterial analyses of surface-outflow samples, Figures 7 and 9, produced more scattered results. Increasing grass and soil establishment again seemed to be more effective in bacterial removal from runoff.

Chemical-oxygen demand, Figures 11 and 12, follows the general pattern of reduction in both grass and soil filtering, with increased filtering in the later trials. This pattern also holds for volatile suspended soilids, Figures 13 and 14. The volatiles, however, initially increased at the early part of the first trial.

Total dissolved solids, Figures 15 and 16, remain relatively constant, and slightly below the inflow value, in each trial run over grass. Subsurface-outflow data show very high salt concentrations, diminishing with later trials. The first two seepage trials show early increases, followed by decreases in salts, while the last two trials show later increases in salts. The trend in dissolved solids content in seepage water decreases with later trials.

SOURCES OF ERRORS

Processes at work in this experiment are very dynamic. Absorption, adsorption, diffusion, dispersion, hydrolosis, ion exchange, migration, miscible displacement, nitrification and solution are kinetic phenomena which vary in time and space, and according to flow rates, soil-water potential and temperature. This measuring and sampling regime probably is not sensitive to all the physio-chemical activity at play. The following examples apply:

1) Likely initial increases in TDS and COD may not appear in the surface-outflow samples because of timing of data collection.
2) Leaching effects are most pronounced with unsaturated flow regimes

of small seepage water volumes.

3) Effects of temperature variations in the lysimeter are lumped in bacterial and COD concentrations of all outflow samples.

INTERPRETATION

Turbidity, suspended and volatile solids, coliforms and COD in runoff samples may be reduced by grass and soil filtration. These water-quality parameters are related, as bacteria may fall out with solids and may comprise some of the organics showing up in COD. The initial increase in coliforms in the early part of the trials over grass probably reflects a grass washing, as high TDS in seepage samples likely represents leaching of soluble minerals. The collection of more water quality data is requisite to concluding that soil-runoff equilibrium is achieved. Increased grass development and soil settling works to produce a better quality effluent.

FUTURE STUDIES

Small ponds were constructed in spring 1972 to hold treated and untreated runoff for observation of biological activity. These ponds may be stocked with algae- or mosquito-eating fish over the summer. A recording rain gage was installed.

Summer runoff events will be diverted to the treatment facility to produce more trials. Bermuda grass will replace rye for the summer. A more detailed analysis will be made of basic data, with a view toward quantifying relationships and identifying biological, chemical and physical soil-water and plant-water processes.

Possibly unsaturated soil-water samples and more spatially distributed samples will be collected by suction cups to delineate zones of water-quality changes, and to evaluate some models of water-quality dynamics through soils.

Pesticide, phenol and trace-element analysis may be performed.

Quantified effects of the water-treatment pilot plant will be used in evaluating the feasibility of the urban runoff management scheme suggested. Perhaps other treatments will be studied. Architectural and legal aspects of constructing a recreational facility on this site are being investigated. Efficiency of treatment will be evaluated by examining water-quality improvement versus unit cost of treatment.

ACKNOWLEDGMENTS

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RELEVANT LITERATURE

Procedures for managing urban runoff in arid lands are discussed by University of Arizona and U.S. Geological Survey (1959), Resnick and DeCook (1970), Mische (1971) and Terlizzi (1972). These studies recognize the influence of water quality on utilization of captured runoff.

Grass filtration for sediment removal is suggested by Wilson and Lehman (1966), Wilson (1967), Lehman (1968) and Wilson (1971). Soil filtration for bacterial removal is suggested by Stone (1953), Bocko (1965) and Merrell and others (1965).

Babcock (1963) synthesized the principles of chemical transfer of waters in contact with soil colloidal systems at equilibrium. Dutt and others (1972) developed computer simulation models of dynamic bio-physiochemical processes in soils.

Some other related work includes Jorden (1962), McCarty (1965), Marsh (1968), Atala (1969), Boyd and others (1969), DeCook (1970), Dharmadhikari (1970) and Mishe and Dharmadhikari (1970).

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