AN ASSESSMENT OF THE IMPACT OF RECREATIONAL DEVELOPMENT OF WATER QUALITY AND YIELD IN SMALL FORESTED WATERSHEDS

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ABSTRACT

The main objective of this study was to determine the effects of second-home development on water quality in small forest watersheds. Research was also done in predicting second-home development in the Cloudcroft, New Mexico area. Different water quality parameters were measured at low and high construction activity sites and compared to a control site using variance and regression analysis. A Kingen 75 simulation model was also used to compare impacts on water quality at different stages of development. Results indicated that the percent total dissolved solids was the key parameter indicating an increase during construction. The infiltration rate proved to be the most sensitive factor tested in the simulation model. Predicted runoff remained constant for all levels of construction except at full development when the actual runoff increased 237 percent in relation to the development at the time. The variables, number of land transactions, the deflated lag price of oil, and the consumer price index for private transportation, were used in combinations for regression analysis and accounted for 90 percent accuracy in determining the variation of second-home development in the Cloudcroft area.

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PROBLEM SITUATION

According to Freeburg, Carruthers and Duncan (8), second-home development with consequent recreational use of surrounding land appears to be alive and well in the Rocky Mountain area, bringing continued concern to those charged with protecting natural resources.

Water is the critical resource in the Rocky Mountain area. Site disturbance associated with the development of "second-homes," such as land clearing, excavation for utility installations, transportation networks, and development of yards, golf courses and other recreational facilities, may affect the water yield of the watershed in which the activity takes place. This disturbance could result in immediate and lasting deleterious impacts on downstream water quality.

Evaluation of these effects rests upon an accurate description of runoff from summer rains. In the semi-arid environment of much of the southern Rocky Mountains, a very long period of record would be required to experience the spectrum of possible rainfall events and their associated runoff events. Under these conditions, calibrated rainfall/runoff simulation provides the most logical means of utilizing existing actual climatic event measurements.

Area Description

Extensive development of vacation home communities has resulted from the natural attraction of the forests and the growth in population surrounding the forested areas. According to Gray and Anderson (9), the growth of recreational uses for these types of areas is illustrated in the prediction that people visiting the Ruidoso (now known as the

Smokey Bear) Ranger District of the Lincoln National Forest would increase from 300,000 in 1960 to 2,000,000 by the year 2000.

Poorly developed vacation-home communities can have detrimental effects on their own and surrounding environments. Layout and construction of roads and associated services can have a detrimental impact on landscape, aesthetics, drainage and erosion. It is important that developers and managers of vacation-home communities have adequate information with which to minimize adverse impacts on the forest environment (7).

The Cloudcroft resource area has been used mainly for recreation purposes such as fishing, golfing, hunting and skiing. Others come seeking relaxation and a change of pace, to rest from the pressure, noise and congestion of the cities.

The Lincoln National Forest is surrounded by desert and semi-arid regions. The yearly precipitation is approximately 20 inches and the elevation at the subdivisions varies from 7,500 to 8,000 feet above sea level (7).

Two of the many private recreational subdivisions near Cloudcroft are Ponderosa Pines and Cloud Country. Each of these subdivisions is bounded generally on the south and west by Forest Service lands.

Resource Considerations

Erosion is most pronounced soon after and during road construction, and including utility installation and excavation for driveways and homesites.

The increase in impervious land and utility systems that are associated with a development accelerate the erosion problem and have significant effects on water quality and yield. The lack of understanding of the environmental problems on the part of managers and/or developers will tend to degrade the environment. Eventually this may have a negative impact on the local economy.

According to Carruthers et al. (4), water deterioration, which limits use beyond the point of origin, impacts severely on public health, fisheries, contact recreation and visual qualities. They identify the principal causal agent as silt and surface materials resulting from vegetation clearing, grading, excavation, blasting and construction on steep slopes. Dirt roads and bare construction sites are a source of large volumes of soil and suspended materials. Construction litter as well as partially decayed solid waste and residue from improperly installed sewage systems result in other kinds of contaminants entering streams. The cumulative effect often can result in high levels of sediment loading and diminution of the aesthetic and recreational values of downsite streams, lakes or man-made reservoirs. The public and/or private costs resulting from these activities can be significant.

McLean and Pullam (15) report that humans have accelerated many geographical changes by landscape transformations of natural areas through cutting, burning, and draining. The changes for construction add to the overall pollution from non-point sources. McElroy et al. (14) regarded sediment resulting from soil erosion as the largest pollutant affecting water quality, with the major contributors being agriculture, silviculture, and construction.

Khanna (13) has established some effects of roads and highways on surface waters. Among the effects cited are: (1) altered storm drainage patterns, (2) increased quantity of runoff, and (3) diminished quality of water. A new road has the potential to disturb the existing pattern of storm drainage in the area by increasing the runoff and cutting through the existing storm drainage pattern. Closely related is the effect on water quality. A highway or road construction project will increase the impervious paved area, thus substantially decreasing the time of flow concentration and increasing the quantity of runoff. This, in turn, results in major increases in peak runoff and storm discharges with consequent degradation of water through erosion and sedimentation.

The high assimulation capacity of the forest community appears to lessen the results of construction and, in time, erosion becomes less pronounced. New construction will aggravate erosion, but this too, will subside in time if proper maintenance is provided (7).

After the construction phase has been completed, newly developed structures will affect runoff. Schneider et al. (19) reported lag time (time of concentration) is reduced as an area becomes urbanized, and storm flow is often concentrated in sharper, shorter, higher peaks than for natural runoff. It was further observed, however, that as flood peaks increses, there is a decline in the ratio of urban peak rate to rural peak rate, with the urbanization being more pronounced for the more frequent occurrences.

Hypotheses and Objectives

The objective of this study is:

To determine whether or not the development of second homes in forest lands has a significant impact on water quality and quantity.

The working hypotheses of this study are:

1. that comparisons between the variances and population means of the water quality samples obtained from the sediment sampler for

Control vs. Pond, and Control vs. Site 101 will reflect significant differences between Control and treatments,

2. that a hydrologic model used to simulate the impact of different stages of development on water quantity at Ponderosa Pines Pond will reflect drastic increases on water quantity as development increases,
3. that most of the variation in the endogenous variables percent total dissolved solids (% TDS), chemical oxygen demand (COD), calcium (CA^{++}), orthophosphate ($PO_4^{=}$) and ammonia nitrogen (NH_4^{+}) is explained by the exogenous variable, accumulated rainfall (ARF), and
4. that second-home development in the area of Cloudcroft, New Mexico can be predicted by an econometric model.

Scope and Limitations

The geographic scope of this study was the Southern Rocky Mountains. Ponderosa Pines, a development near Cloudcroft, New Mexico (Figure 1), was chosen from several sites as being a representative typical site for intensive study. Some data is also included from Cloud Country, a development near Ponderosa Pines. The procedures and analytical techniques used in this study should be applicable to studies of other

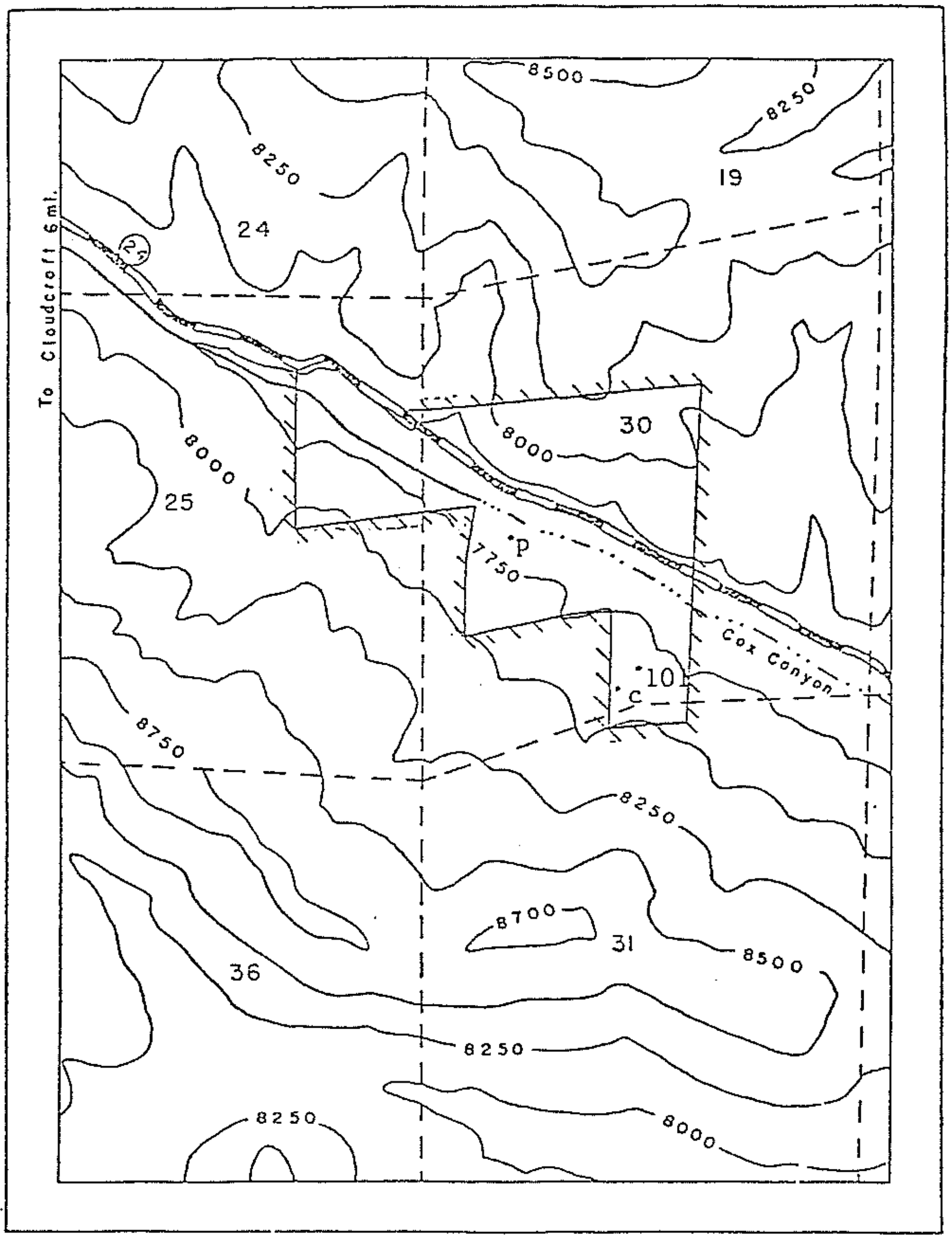

Figure 1. Ponderosa Pines development, topographic relief and spatial orientation.

similar second-home development sites. Cloud Country and Timberon are examples of similar sites where these procedures and techniques might be applied.

The scope of this study was limited by the length of the research period. A longer period of records is required in much of the southern Rocky Mountains in order to experience the spectrum of possible rainfall events and second-home developments. Mechanical failures also contributed to the lack of additional data points.

In spite of the major limitation (time constraint) in the scope of this study, the results are believed to be representative and the procedures and techniques used are applicable to similar development areas.

METHODS AND PROCEDURES

Ponderosa Pines is located approximately eight miles southeast of Cloudcroft (the nearest town) in Cox Canyon. Roads have been graveled. A golf course, with club house, and a fishing pond have been developed. In 1980, 78 percent of the lots at this site had been sold and 10 percent had buildings on them. Most of this construction was concentrated in the area near the research monitoring site labeled "Pond." This is the most active development site studied.

Cloud Country is located east of Cloudcroft in James Canyon. A recreational hall, horse stables, tennis courts, swimming pool and landing strip have been developed in Cloud Country. All of the roads have been roughed out and some have been paved. Utilities, consisting of a water and fire system, electrical system, sewage system and telephone system, have been installed.

In order to measure the impact of second-home development on water quality and quantity, it was necessary to select and monitor the study area for levels of the water quality parameters. The impact was measured by simulating different stages of development and calibrating the simulation by analysis of the collected water samples for the water quality parameters cited in the research literature. Comparison between site conditions for the different parameters was made by using the test of hypotheses technique. More specifically, the hypotheses were tested by using the *F*-test and *t*-test. Also, simple and multiple linear regression were used in an attempt to measure the relationship between water quality parameters and accumulated rainfall.

Site Selection

Ponderosa Pines was selected as the site for intensive study based on a predetermined set of criteria. The criteria for selection were:

1. anticipated high build-up rates or on-going construction of second homes and/or recreational facilities,
2. willingness of owner-developers to cooperate with researchers and to permit placement of monitoring equipment in small watersheds,
3. existence of land-use plans reflecting the expected pattern of development, roads and natural resources present, and
4. diversity of slope, soil types and vegetative cover.

Ponderosa Pines was divided into three watersheds: Control, Pond and Site 101. Some development has taken place at Pond and Site 101 watersheds while the Control watershed has remained undisturbed.

Water Quality Parameter Definitions

The term "polluted" is of necessity a relative description since any constituent carried in water might be considered a pollutant if it is present in excessive concentrations. Polluted" and "unpolluted" water carry many of the same constituents, but in polluted water one or more exist in undesirable concentrations.

According to Pavoni (17), the water quality parameters routinely used to indicate pollution are: suspended solids, biochemical oxygen demand, chemical oxygen demand, nitrogen, phosphorous and bacteria.

Suspended solids are matter carried in suspension, as opposed to other dissolved solid matter in solution or colloidal dispersion. Together, the classification of "suspended" and "filterable" describe the total solids content of wastewater.

Analytically, the total solids content is that matter which remains as residue after evaporation of the wastewater at 103°C or 105°C. Naturally, matter having a significant vapor pressure at these temperatures will evaporate and not be included in the total solids analysis. All the forms of solids may have detrimental effects on water quality if present in excessive concentrations. Dissolved solids levels may make the water unsuitable for certain uses, while colloidal and suspended solids content may increase turbidity, thereby decreasing light penetration into the water and inhibiting aquatic growth (17).

The total amount of oxygen which would be consumed if all the oxidizable matter were oxidized is referred to as the theoretical oxygen demand. This demand can be calculated from the stoicheometry of the oxidation equation of the specific compounds in the wastewater.

Various analytical procedures are available to measure the oxygen demand of wastewater. The two major techniques currently utilized are the biochemical oxygen demand (BOD) and the chemical oxygen demand (COD). The former is a bioassay procedure, while the latter is a chemical digestion process. Both have significant interpretations though they cannot always be directly related to one another (17).

BOD is an empirical bioassay procedure. It measures the dissolved oxygen consumed by microbial life while assimilating and oxidizing the organic matter present. The standard test includes dark incubation at 20°C for a specific time period (often five days).

COD is a rigorous, high temperature, acidic, chemical digestion process, in which oxygen-demanding material is consumed by a powerful oxidizing agent (potassium dichromate). A sample of the wastewater, or an appropriate dilution, is mixed with a precisely measured amount of potassium dichromate solution and concentrated sulfuric acid. The sample is then heated and refluxed for a specified time period (usually two hours). The amount of potassium dichromate remaining after digestion is measured by titration and is an inverse measure of the oxygen demand of the wastewater. Any organic or inorganic compound present in the wastewater which is capable of being oxidized in the test conditions will be included in the COD determination (17).

Miner (16) has shown that presence of cattle may increase concentration of bacteria in runoff and may alter total oxygen demand in receiving streams. Bansal (1) reported that the oxygen demand of nitrogenous wastes (such as microbiologically degraded cow manure) substantially stresses the oxygen resources of a slowly reaerating system.

Nitrogen occurs in domestic wastewaters primarily in the ammonia and organic nitrogen forms. Contributions from inorganic nitrogen forms (nitrate and nitrite nitrogen) are usually negligible. However, there may be a measurable concentration of inorganic nitrogen following biological treatment, when a portion of the ammonia nitrogen is oxidized by the microorganisms to inorganic nitrogen forms. Organic nitrogen normally exists in wastewater as proteins and nucleic acid components arising primarily from excreta and foodstuffs. Urea in urine and the biodegradation of organic nitrogen account for the presence of ammonia nitrogen in wastewater.

Inorganic nitrogen is measured by colorimetric test procedures. Ammonia nitrogen is measured by boiling off the ammonia from a slightly alkaline solution of the waste, capturing it in an acid solution and measuring its concentration by titration or colorimetry. Organic nitrogen is measured by digestion of the waste in a highly acidic solution, which converts the organic nitrogen to ammonia, which can then be measured by the procedure above. The Total Kjeldahl Nitrogen Procedure measures the organic and ammonia nitrogen forms together. The sum of all the nitrogen forms (ammonia, organic, and inorganic) are known as the Total Nitrogen content of the wastewater.

Nitrogen in treatment plant effluent contributes to eutrophication problems. In addition, organic and ammonia nitrogen may be metabolized by bacteria, causing an oxygen demand in the receiving water. Ammonia nitrogen also consumes chlorine during the chlorination process, thereby inhibiting disinfection (17).

Poorly constructed golf course greens often have a low infiltration rate, and excess water may run off the surface. Water lost from golf greens through runoff or leaching carries with it nitrogen from the fertilizer as either nitrate or ammonia. Nitrate is known to cause eutrophication of lakes and can be harmful to humans and livestock if consumed in drinking water.

The amount of nitrate that may be lost from golf greens will depend on many factors. Among them are the nitrogen source in the fertilizer applied, the time between fertilizer applications, the amount of irrigation or rainfall, the infiltration rate of the greens mixture and the season of the year (soil temperature).

Brown, Duble and Thomas (2) noticed that when organic or slow release forms of fertilizers, including isobutylidene diurea (IBDU), urea formaldehyde and sewage sludge (Milorganite), were applied, the concentrations of nitrate found in the leachate were always low and water met EPA standards for drinking water. It was evident from the results of the study that the use of inorganic fertilizer sources resulting in economic loss and environmental hazards can be avoided by the use of slow release organic forms.

Phosphorus exists in wastewater as inorganic phosphate ions (PO_4^{3-}), $HPO_4^{=}$, $H_2PO_4^{-}$ and polyphosphate polymers) and as organic phosphates. The organic phosphate is bound in organic molecules, such as RNA, DNA and nucleotides, while the inorganic phosphate exists as ions in solution. In normal wastewater (pH 6.8-7.2) the predominant inorganic ions are $HPO_4^{=}$ and $H_2PO_4^{-}$.

The concentration of phosphate ions in water can be measured colorimetrically by the formation of a blue complex. Polyphosphates and organic phosphates are converted to phosphate ions by chemical digestion and then measured colorimetrically.

The sources of phosphorus in wastewater are excreta, food wastes and synthetic detergents. More than half the concentration of phosphorous in domestic wastewater can be attributed to detergents in which phosphates are used as "builders" to enhance detergent action.

The importance of effluent phosphorus levels is their effect on eutrophication of the receiving waters (17).

Data Collection

The data was collected by installing instruments on all three small watersheds. H-flumes, stage recorders, recording rain gauges, accumulating rain gauges and sediment samplers were installed. The recording rain gauges were the tipping-bucket type. The accumulating rain gauges were inexpensive aluminum cans opened at the top and funneled at the bottom to collect the precipitation and pass it to a plastic storage bottle in a well beneath the can.

The sediment samplers consisted of a ventilated plastic elbow attached to the top of a canning jar. The elbow pointed into the stream and was set approximately five centimeters above the bottom of a v-notch in the weir placed in the watershed course. The samplers usually fill at only one stage of flow; i.e., immediately after the water surface reaches the throat of the well. This characteristic of the sampler is important in explaining the size distribution of the collected samples. Doty and Carter (5) noted that clay-sized particles are usually high at the beginning of a runoff event and decrease as the soil-loss rate increases, while the reverse is true for silt-sized particles. Runoff samples were analyzed for percent total dissolved solids (% TDS), chemical oxygen demand (COD), calcium (CA^{++}), orthophosphates ($PO_4^{=}$), ammonia nitrogen (NH_4^{+}), pH, conductivity, total hardness, nitrate nitrogen, total chlorine and suspended solids. Tables 1 through 4 show the water quality data selected for this study. Most of the data were collected during the summer of 1979. Additional data from 1974 and 1975 were utilized from a previous study by Freeburg and Buchanan (7).

Water Quality Parameters Comparison of Variances and Means

The t distribution is appropriate rather than the Z for normally distributed populations in problems involving the testing of hypotheses about the population mean or differences between means, if the sample size is less than 30 and the value of the standard error has been calculated on the basis of sample data (12). In addition, the two- sample t-test assumes that the variances of the two variables are equal ($\sigma_1^2 = \sigma_2^2$)

The hypothesis to be tested is:

H_0: $U_1 = U_2$ (Population means are equal)

H_A: $U_1 \neq U_2$

If the variances are assumed to be equal, then the t statistic would be:

$$\text{t-cal.}(n_1 + n_2 - 2) = \{(\bar{X}_1 - \bar{X}_2) - (U_1 - U_2)\}/\sqrt{S_p^2\ (n_1 + n_2)/(n_1 \times n_2)}$$

$$S_p^2 = [(n_1 - 1)\ S_1^2 + (n_2 - 1)\ S_2^2]/(n_1 + n_2 - 2)$$

and, degree of freedom = $n_1 + n_2 - 2$ (10). The null variance is distributed as a chi-square. If the variances are not known and assumed different ($\sigma_1^2 \neq \sigma_2^2$) the ratio of the variances remains as a parameter in the test criterion, and is not distributed as a Student's t (21). Consequently, one resorts to an approximate solution. Fortunately, the t-test is a fairly "robust" test, so that deviations from the above assumptions (that is, the assumption of normality and equality of variances) may not destroy the usefulness of this approach (10). The following approximation, from Snedecor and Cochran (20), uses the ordinary t-table, and is sufficiently accurate.

Case 1: If $n_1 = n_2 = n$, calculate t in the usual way, but give it $(n - 1)$ d.f. instead of $2(n - 1)$.

Case 2: If $n_1 \neq n_2$, calculate t, which is given by;

$$t_1' = \{(X_1 - X_2) - (U_1 - U_2)\} / \quad (S_1^2/n_1) + (S_2^2/n_2)$$

To test for equality or inequality of variances, a ratio, rather than a difference, is used. The hypothesis to be tested is:

H_0: $\sigma_1^2 = \sigma_2^2$ (Population variances are equal)

H_A: $\sigma_1^2 \neq \sigma_2^2$

Then;

Fcal. (ν_1, ν_2) = ratio of larger estimate of σ^2 over smaller estimate of σ^2; Fcal. is then compared to a tabulated F value for the respective degrees of freedom for the numerator and denominator. If Fcal. is less than Ftab., then the null hypothesis that the variances are equal ($\sigma_1^2 = \sigma_2^2$) is accepted; if not, the null is rejected (21).

Table 1. Selected water quality parameters, dates of monitoring and descriptive statistics for Control site[a] at Ponderosa Pines.

Date	% TDS	Accumulated Rainfall	COD	CA^{++}	$PO_4^{=}$	NH_4^{+}
		(mm.)		(mg./l.)		
10/01/74[b]	1.200	185	--	--	--	--
07/15/75[b]	1.470	180	--	--	--	--
08/06/75[b]	0.780	71	--	--	--	--
09/16/75[b]	5.520	--	--	--	--	--
08/13/79	0.150	62	26	25	1.10	2.00
08/21/79	0.022	14	123	20	--	--
09/03/79	0.039	17	90	20	0.50	2.20
09/14/79	0.072	35	46	30	0.50	2.20
09/16/79	0.030	45	577	20	0.10	0.60
Sample Size	9	8	5	5	4	4
Sample Mean	1.0314	76.125	172.40	23.00	0.55	1.75
Sample Variance	3.1419	4697.8393	52585.30	20.00	0.17	0.5967

[a] Construction activity level is none.

[b] Source: Freeburg, Robert S. and Bruce A. Buchanan, Impact of Roads in Recreational Developments on Forest Environment, Final Report on Eisenhower Consortium Cooperative Agreement 16-432-CA, New Mexico State University, Las Cruces, p. 9, 1974 and 1975 data.

Table 2. Selected water quality parameters, dates of monitoring and descriptive statistics for site 101[a] at Ponderosa Pines.

Date	% TDS	Accumulated Rainfall	COD	CA^{++}	$PO_4^{=}$	NH_4^{+}
		(mm.)		(mg./l.)	-	
08/27/74[b]	9.74	61	--	--	--	--
10/01/74[b]	10.00	185	--	--	--	--
07/15/75[b]	5.44	180	--	--	--	--
08/06/75[b]	7.95	71	--	--	--	--
09/03/75[b]	17.51	91	--	--	--	--
09/16/75[b]	19.61	--	--	--	--	--
10/14/75[b]	10.86	15	--	--	--	--
07/18/79	--	38	--	--	--	--
07/23/79	--	38	--	--	--	--
07/24/79	--	27	--	--	--	--
07/26/79	2.32	27	1943	90	0.18	1.10
08/04/79	--	34	--	70	0.10	1.45
08/08/79	1.58	46	79	85	0.15	0.85
08/11/79	--	45	--	70	0.05	1.40
08/13/79	0.57	62	53	60	0.18	0.80
08/16/79	0.58	73	146	70	0.30	0.40
08/21/79	0.66	14	244	70	0.10	0.50
09/03/79	1.84	17	23	70	0.10	0.08
09/14/79	0.66	35	46	85	0.10	0.60
09/16/79	0.71	45	692	100	0.10	0.50
Sample Size	15	19	8	10	10	10
Sample Mean	6.002	58.1053	403.25	77	0.136	0.84
Sample Variance	40.6926	2349.7661	435110.79	151.111	0.0050	0.1377

[a] Construction activity level is high.

[b] Source: Freeburg, Robert S. and Bruce A. Buchanan, Impact of Roads in Recreational Developments on Forest Environment, Final Report on Eisenhower Consortium Cooperative Agreement 16-432-CA, New Mexico State University, Las Cruces, p. 9, 1974 and 1975 data.

Table 3. Selected water quality parameters, dates of monitoring and descriptive statistics for Pond[a] site at Ponderosa Pines.

Date	% TDS	Accumulated Rainfall	COD	CA^{++}	$PO_4^{=}$	NH_4^{+}
		(mm.)		(mg./l.)	-	
07/24/79	--	27	--	90	0.04	0.7
07/26/79	0.19	27	1257	80	0.37	1.5
08/16/79	0.41	73	146	80	0.18	0.7
09/14/79	0.13	35	68	80	0.20	0.8
09/16/79	0.13	45	654	90	0.20	1.2
Sample Size	4	5	4	5	5	5
Sample Mean	0.215	41.40	531.25	84.00	0.198	0.98
Sample Variance	0.0177	366.80	301599.58	30.00	0.0137	0.127

[a] Construction activity level is high.

Table 4. Selected water quality parameters, dates of monitoring and descriptive statistics for site 101 and Ponderosa Pines site Pond.

Date	% TDS	Accumulated Rainfall	COD	CA^{++}	$PO_4^{=}$	NH_4^{+}
		(mm.)		(mg./l.)	-	
Sample Size	19	24	12	15	15	15
Sample Mean	4.7837	54.625	445.9167	79.3333	0.1567	0.8867
Sample Variance	37.5281	1950.7663	363114.99	117.3810	0.0080	0.1295

Source: Aggregation of tables 2 and 3.

Regression analysis is an appropriate technique to be used when measuring the relationship between a dependent variable, Y, and one or more independent variables, x_1, x_2,....x_n. The technique requires a great deal of statistical data which could be difficult to obtain. If multicollinearity or heteroscedasticity is present, the estimates of the parameters will be biased (11). The model can be statistically tested by a standard technique to find if it has predictive potential or to find if the variables are statistically significant.

KINGEN 75 SIMULATION MODEL

The impact of second-home development on water yield at Ponderosa Pines Pond watershed was measured by simulating runoff for different stages of construction development. Kingen 75 is a simulation model designed to have the capability of predicting storm runoff from watersheds for discrete periods of time, that is, for several hours to no more than one or two days (18). Planes, such as roads, roofs and parking lots or terrain, may be impervious. Thus, this attribute of the model accommodates the changing nature of the environment as housing development occurs.

Characteristics of the Model

The model can compute flow for the following geometrical segments: overland flow over a rectangular impervious surface, overland flow over a rectangular pervious surface with an infiltration component to compute rainfall excess, open channel flow in a trapezoidal-shaped channel and tree surface flow in a circular conduit (18). Ponderosa Pines Pond watershed geometry is represented by combinations of the segments mentioned above. The parameters for the computer model are provided or estimated from available information about the watershed. The basic inputs required include:

1. a hydrograph of precipitation for the watershed,
2. an accurate characterization of the geometry and topography of the area (length, width, slope, channel dimensions),
3. measure of two parameters which relate to surface roughness and the flow regime (laminar or turbulent), and
4. the infiltration characteristics of pervious planes.

This information was obtained for Ponderosa Pines Pond from topographic maps, watershed reconnoissance, monitoring of the area with H-flumes, stage recorders and rain gauges, aerial photographs, soil surveys, and property development records. However, for other areas, other sources which contain hydrologic information could be used.

The input data described above is used by the simulation model to sequentially compute the outflow hydrograph from each segment. Thus, Ponderosa Pines Pond watershed was segmented into a series of planes which cascade onto other planes. The computation begins on the segment at the highest elevation of the watershed and continues down slope to the lowest point on the watershed.

ANALYSIS, RESULTS AND INTERPRETATIONS

The following descriptive analysis describes an initial evaluation of the impact of second-home development. The *F*-statistic and *t*-statistic were used to test the first hypothesis of this study. The Kingen 75 simulation model was used to test the second hypothesis. The regression analysis was used to test the third hypothesis. These procedures or techniques were used to achieve the objective set forth in chapter one.

Descriptive Analysis

An initial evaluation of the impact of second-home development was made from monitoring data and the sequence of construction activity plotting the percent total dissolved solids against time. The data points were arranged relative to key construction activities when possible. Three examples of this descriptive analysis are presented in figures 2, 3 and 4. They reflect the relative high temporal variation in percent total dissolved solids at Ponderosa Pines as that site matured into an established second-home development. Measurements were taken during the typical growing season of July through October. Figure 2 shows for site 101 how the percentage of total dissolved solids increases with road construction. It reaches its maximum just before the end of the road construction activity and then declines. This activity took place during 1974 and 1975. Later, during the summer of 1979, the percentage of total dissolved solids increased in conjunction with road resurfacing. It was relatively less pronounced and reached its maximum just before the end of the road resurfacing. Figure 3 shows the construction activity and fluctuations of percentage total dissolved solids at Ponderosa Pines, site Pond, for the summer of 1979. There was an increase in the percentage of total dissolved solids after a telephone line ditch was dug reaching a maximum just before the ditch was backfilled. It declined after the soil had been compacted.

A comparison among the three sites is presented in figure 4. The generation of excess total dissolved solids is in response to perturbations caused by construction activities.

The self-healing capabilities of the forest can be seen by comparing the total solids production in 1974-75 to that in 1979 (figure 2). The

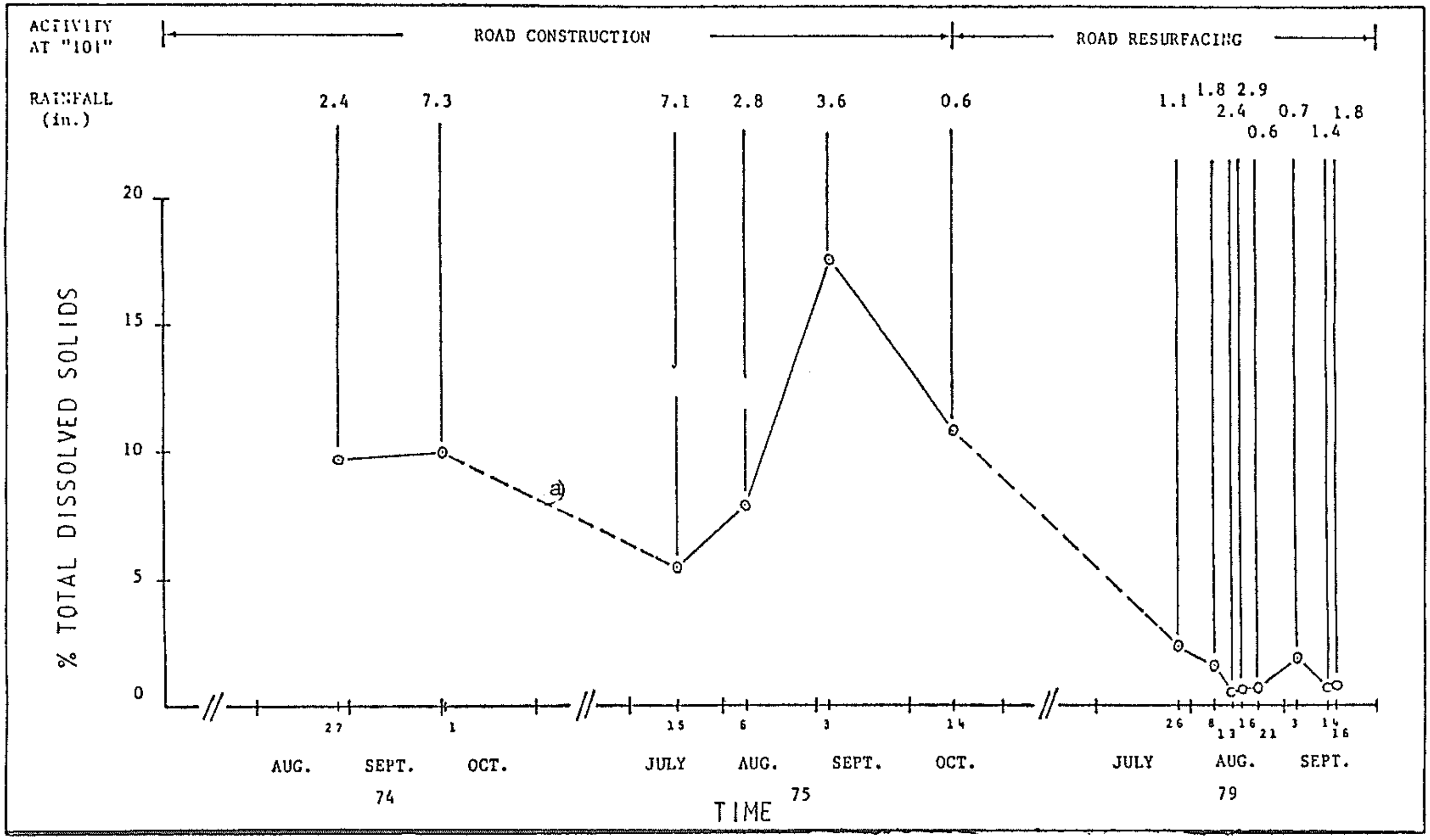

Figure 2. Percent total dissolved solids production at Ponderosa Pines site 101 for each rainfall event and type of activity.

a) The dotted lines signify the discontinuity of data measurement.

b) Source: Table 2.

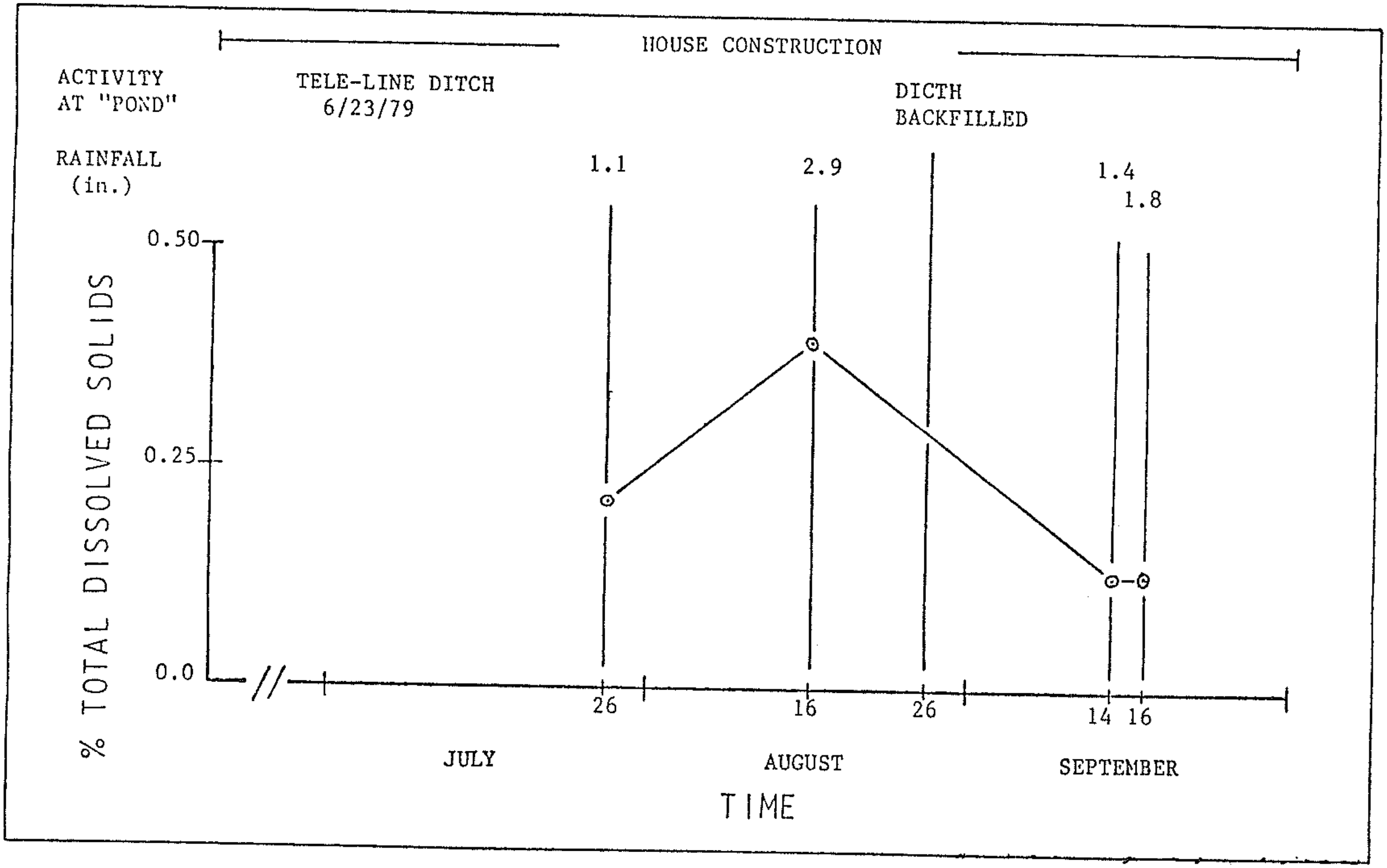

Figure 3. Percent total dissolved solids at Ponderosa Pines site pond for each rainfall event and type of activity during the summer of 1979.

a) Source: Table 3.

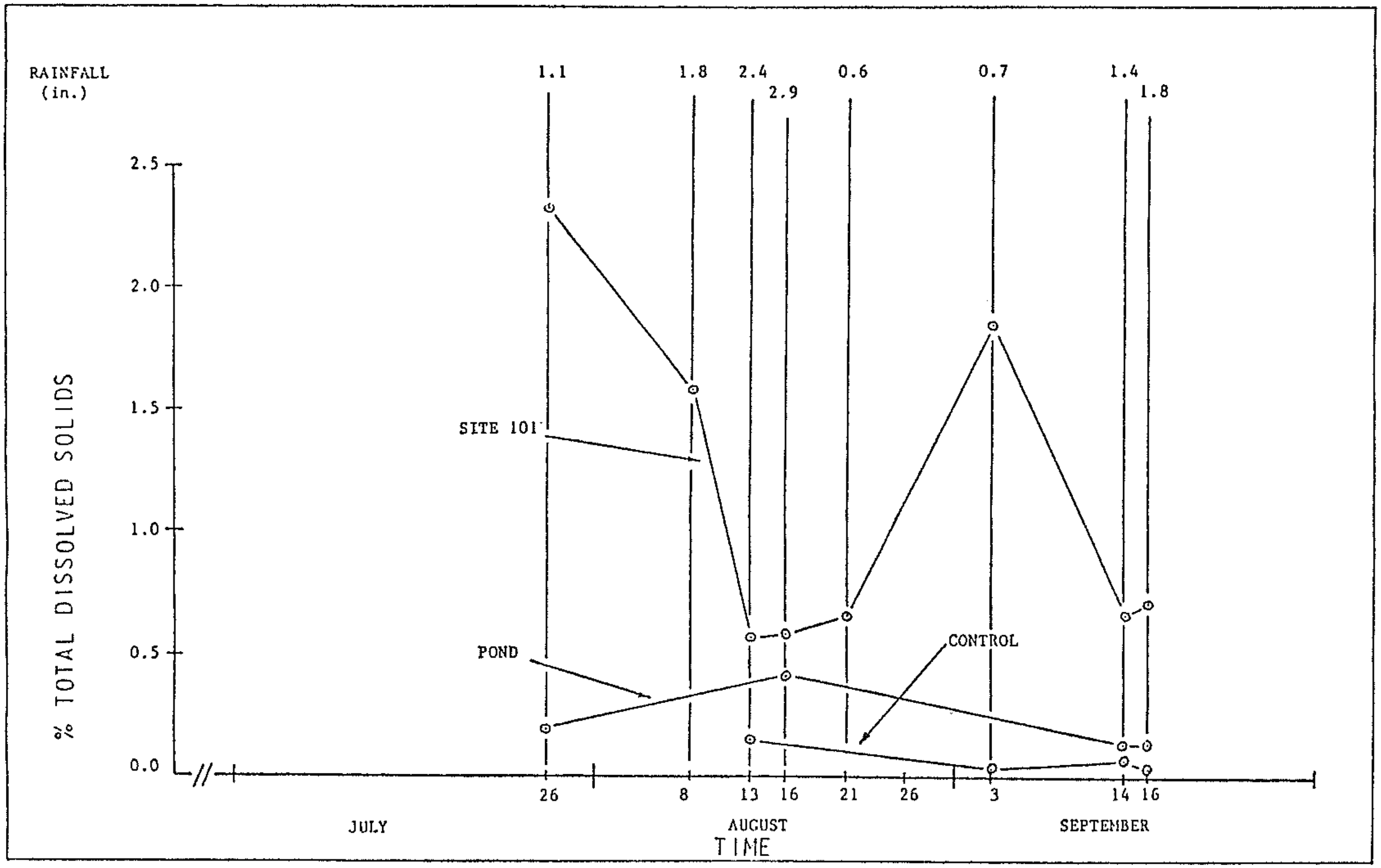

Figure 4. Percent total dissolved solids production at Ponderosa Pines Sites 101, Pond and Control. Summer of 1979.

a) Sources: Tables 1, 2 and 3.

healing process goes from 17.5 percent total dissolved solids to 1.8 percent total dissolved solids. This effect is evident in figures 2 and 4 and applies to long-term as well as seasonal time.

Some severe perturbations remain for long periods. One such long-term disturbance is the bulldozer track above Site 101 made in 1974. This track was made by moving the machine directly up a water course, from one contour road to the next higher one. After five years, the track is very pronounced even though there has been no further construction in the area. The quantitative meaning of this perturbation is shown in figure 4, where a comparison was made among the three Ponderosa Pines sites. There is undeveloped national forest above the site Control area and road maintenance was the only construction activity at site 101 during 1974. Percent total dissolved solids production has remained higher at site 101 than at either Pond or Control.

Water Quality Parameter Comparison Among the Different Sites

This section of analysis describes the tests for the first hypothesis of this study. Comparisons between the population variances and population means of the water quality parameters were made for site Control vs. site 101, site Control vs. site Pond, and site Pond vs. site 101. The hypothesis stated that these comparisons would reflect significant differences between Pond and site 101 with respect to the Control. Two comparisons are presented below as examples. These examples demonstrate how the summary results presented in tables 5 and 5a were obtained.

Examples:

1. Control vs. Site 101

   The hypothesis tested for percent total dissolved solids (% TDS) was:

Table 5. F-test variance of water quality parameters comparison between sites at Ponderosa Pines development[a].

	Comparison					
Parameter	Control (none) vs. Site 101 (low)		Control (none) vs. Pond (high)		Pond (high) vs. Site 101 (low)	
% TDS	Fcal.(14,8)=12.951 vs. Ftab.(14,8)=12.951	S***	Fcal.(8,3)=177.5098 vs. Ftab.(8,3,0.005)=44.13	S***	Fcal.(14,3)=2299.02 vs. Ftab.(14,3,0.005)=43.09	S***
COD	Fcal.(7,4)=8.274 vs. Ftab.(7,4,0.05)=6.09	S*	Fcal.(3.4)=5.735 vs. Ftab.(3,4,0.05)6.59	NS	Fcal.(7,3)=1.443 vs. Ftab.(7,3,0.05)=8.89	NS
$PO_4^=$	Fcal.(3,9)=34.121 vs. Ftab.(3,9,0.005)=8.72	S***	Fcal.(3,4)12.391 vs. Ftab.(3,4,0.025)=9.98	S**	Fcal.(4,9)=2.754 vs. Ftab.(4,9,0.05)=3.63	NS
NH_4^+	Fcal.(3,9)=4.334 vs. Ftab.(3,9,0.05)=3.86	S*	Fcal.(3,4)=4.698 vs. Ftab.(3,4,0.05)=6.59	NS	Fcal.(9,4)=1.084 vs. Ftab.(9,4,0.05)=6.00	NS

[a] The construction activity level is given in parenthesis.

NS = Non-significant at α = 05.

S* = Significant α = .05.

S** = Highly significant α = .025.

S*** = Very highly significant α = .005.

Table 5a. t-test mean comparison of water quality parameters between sites at Ponderosa Pines development[a].

		Comparison							
Parameter		Control (none) vs. Site 101 (low)			Control (none) vs. Pond (high)			Pond (high) vs. Site 101 (low)	
% TDS	$(\sigma_c^2 \neq \sigma_{101}^2)^b$	t-cal.=2.841 vs. t-tab.=±3.020	S*	$(\sigma_c^2 \neq \sigma_p^2)$	t-cal.=+1.373 vs. t-tab.=±3.386	NS	$(\sigma_p^2 \neq \sigma_{101}^2)$	t-cal.=-3.511 vs. t-tab.=12.982	S**
COD	$(\sigma_c^2 \neq \sigma_{101}^2)$	t-cal.=-0.906 vs. t-tab.=±2.432	NS	$(\sigma_c^2 = \sigma_p^2)$	t-cal.=-1.340 vs. t-tab.=±2.365	NS	$(\sigma_p^2 = \sigma_{101}^2)$	t-cal.=+0.407 vs. t-tab.=±1.812	NS
$PO_4^=$	$(\sigma_c^2 \neq \sigma_{101}^2)$	t-cal.=+1.997 vs. t-tab.=±5.811	NS	$(\sigma_c^2 \neq \sigma_p^2)$	t-cal.= 1.655 vs. t-tab.=±4.493	NS	$(\sigma_p^2 = \sigma_{101}^2)$	t-cal.= 1.292 vs. t-tab.=2.16	NS
NH_4^+	$(\sigma_c^2 \neq \sigma_{101}^2)$	t-cal.=2.254 vs. t-tab.=±3.104	NS	$(\sigma_c^2 = \sigma_p^2)$	t-cal.= 2.003 vs. t-tab.=±2.365	NS	$(\sigma_p^2 = \sigma_{101}^2)$	t-cal.=+0.697 vs. t-tab.= 2.160	NS

[a] The construction activity level is given in parenthesis.

[b] The variance comparison figures in parenthesis come from table 5.

NS = Non-significant difference at α = 0.05.

S* = Significance difference at α = 0.02.

S** = Significance difference at α = 0.01.

H_0: $\sigma_c^2 = \sigma_{101}^2$ (Population variances are equal)

H_A: $\sigma_c^2 \neq \sigma_{101}^2$

$$S = (\Sigma Y^2 - (\Sigma Y)^2/n)/(n - 1)$$

$$S_c^2 = 3.1419238$$

$$S_{101}^2 = 40.692603$$

F-cal.(14.8) = 40.692603 / 2.1419238 = 12.951

Ftab.(15,8,0.005) = 6.81

F-cal. is greater than F-tab, which means that F-cal. falls in the rejection region of the distribution. Thus, we reject the null hypothesis based on the data given and conclude that the population variances for the two sites are not equal.

Now, the hypothesis to be tested is:

H_0: $U_c = U_{101}$ (Population means are equal)

H_A: $U_c \neq U_{101}$

Since $\sigma_c^2 \neq {}_{101}^2$

then,

$$t_1' = = (1.031444 - 6.002) / \sqrt{(3.1419238/9) + (40.692603/15)}$$

$$t_1' = -2.841$$

$$t(8,0.02) = 2.896$$

$$t(14,0.02) = 2.624$$

$$t_2' = \frac{(3.1419238/9)(2.896) + (40.6926\text{-}3/15)(2.624)}{(3.1419238/9) + (40.692603/15)}$$

$$t_2' = \pm 2.655$$

t_1' falls outside the interval ±2.655. Thus, the null hypothesis is rejected and one concludes that the two population means are not equal.

2. Control vs. Pond

The hypothesis tested for chemical oxygen demand (COD) was:

H_0: $\sigma_c^2 = \sigma_p^2$

H_A: $\sigma_c^2 \neq \sigma_p^2$

F-cal.(3,4) = 301599.58 / 52585.30 = 5.735

F-tab.(3,4,0.05) = 6.59

F-cal. is less than F-tab. which means that F-cal. falls in the acceptance region of the F-distribution. Thus, we accept the null hypothesis and conclude that the two population variances are equal.

Now, the hypothesis to be tested is:

H_0: $U_c = U_p$

H_A: $U_c \neq U_p$

Since $\sigma_c^2 = \sigma_p^2$

Then,

$$\text{t-cal.}(4+5-2) = (531.25 - 172.40) \,/\, \sqrt{S_p^2\ (4+5)/(4\text{x}5)}$$

$$\text{t-cal.}(7) = 358.85 \,/\, \sqrt{S_p^2\ (9/20)}$$

$$S_p^2 = \{(3)(301599.58) + (4)(52585.30)\} \,/\, (4+5-2)$$

$S_p^2 = 159305.7057$

Thus,

t-cal.(7) = -1.3371

t-tab. (7,0.05) = ±2.365

t-cal. falls inside the acceptance region ±2.365. Thus, the null hypothesis is accepted and one concludes that the two population means are equal.

The two examples were provided to show how the two population means were compared when the two population variances were equal and when they were not equal.

Tables 5 and 5a present the statistical significance levels for the water quality parameters between the different sites. The results presented in tables 5 and 5a indicate the following:

1. Control vs. Site 101: The population variances (table 5) were significantly different even at the 0.005 significance level for percent total dissolved solids and orthophosphates. The population variances of chemical oxygen demand and ammonia nitrogen of the two sites were significantly different at an alpha level of 0.05. The population means (table 5a) of percent total dissolved solids of the two sites were significantly different at an alpha level of 0.02. The other water quality parameters were not significantly different at an alpha level of 0.05.
2. Control vs. Pond: The population variances for percent total dissolved solids were different at the 0.005 significance level. The population variances for orthophosphate were significantly different at the 0.025 level. The population variances

of chemical oxygen demand and ammonia nitrogen for the two sites were not significantly different at the 0.05 significance level. The population means of all the water quality parameters for the two sites were not significantly different at the 0.05 significance level.

3. Site Pond vs. Site 101: The population variances for percent total dissolved solids were different at the 0.005 significance level. The population variances of the other water quality parameters for the two sites were not significantly different at the 0.05 significance level. The population means of percent total dissolved solids at the two sites were significantly different at the 0.01 significance level. The population means of the other water quality parameters for the two sites were not different at the 0.05 significance level.

Even though site Pond had a higher construction activity level than site 101 and site Control had no construction, site 101 had a higher percent total dissolved solids than either site Pond or site Control, probably due to the track made by the bulldozer.

The results show that there is no significant difference between the means of the site Control and site Pond sites for percent total dissolved solids, chemical oxygen demand, orthophosphates, and ammonia nitrogen. The results also show a significant difference for percent total dissolved solids between sites Control and site 101, being much higher at site 101. Chemical oxygen demand, orthophosphates, and ammonia nitrogen are not significantly different between the three sites, Control, Pond, and site 101. Thus, the results indicate that percent total dissolved solids is the only water quality parameter significantly different between Control and site 101, and between site Pond and site 101.

Simulation

This section of the analysis describes the test for the second hypothesis set forth: that a hydrologic model used to simulate the impact of different stages of development on water runoff will reflect drastic increases of water runoff as development increases.

The Kingen 75 simulation model was used to simulate hydrographs for Ponderosa Pines Pond under various levels of development. Ponderosa Pines Pond was selected because both rainfall depth and runoff data were available. The different stages of development simulated were as follows:

*Simulation 1 -- No development, (figure 5).

*Simulation 2 -- Road only, (figure 6).

*Simulation 3 -- Road and parking lot, (figure 7).

*Simulation 4 -- Development at the time of measurement, (figure 8).

*Simulation 5 -- Full development, (figure 9).

The model was calibrated during Simulation 4. The predicted values were compared with the actual value to establish the validity of the model for very small watersheds and to calibrate the model for the Ponderosa Pines site Pond. See Table 9 for calibration results for representative large and small runoff events. In the calibration process a number of factors were varied to test model sensitivity in small watersheds. The parameter perturbation form of analysis was used, i.e., one parameter was varied while the others were held constant and the result was recorded. The infiltration rate (Fmin) was proven to be the most sensitive factor.

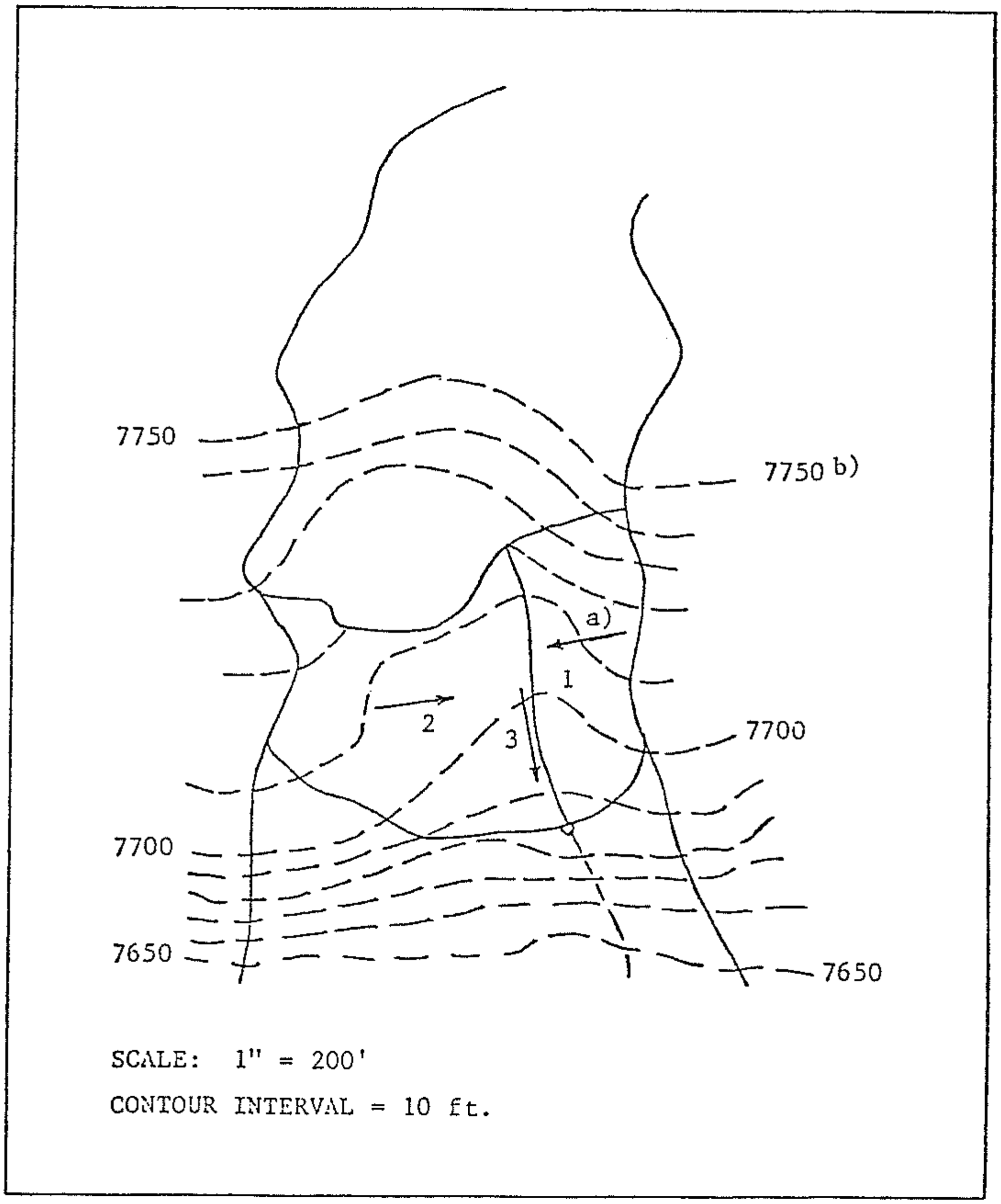

Figure 5. Ponderosa Pines site Pond watershed, no development stage.

a) The arrows indicate the direction of flow.
b) The dotted lines represent contour lines.

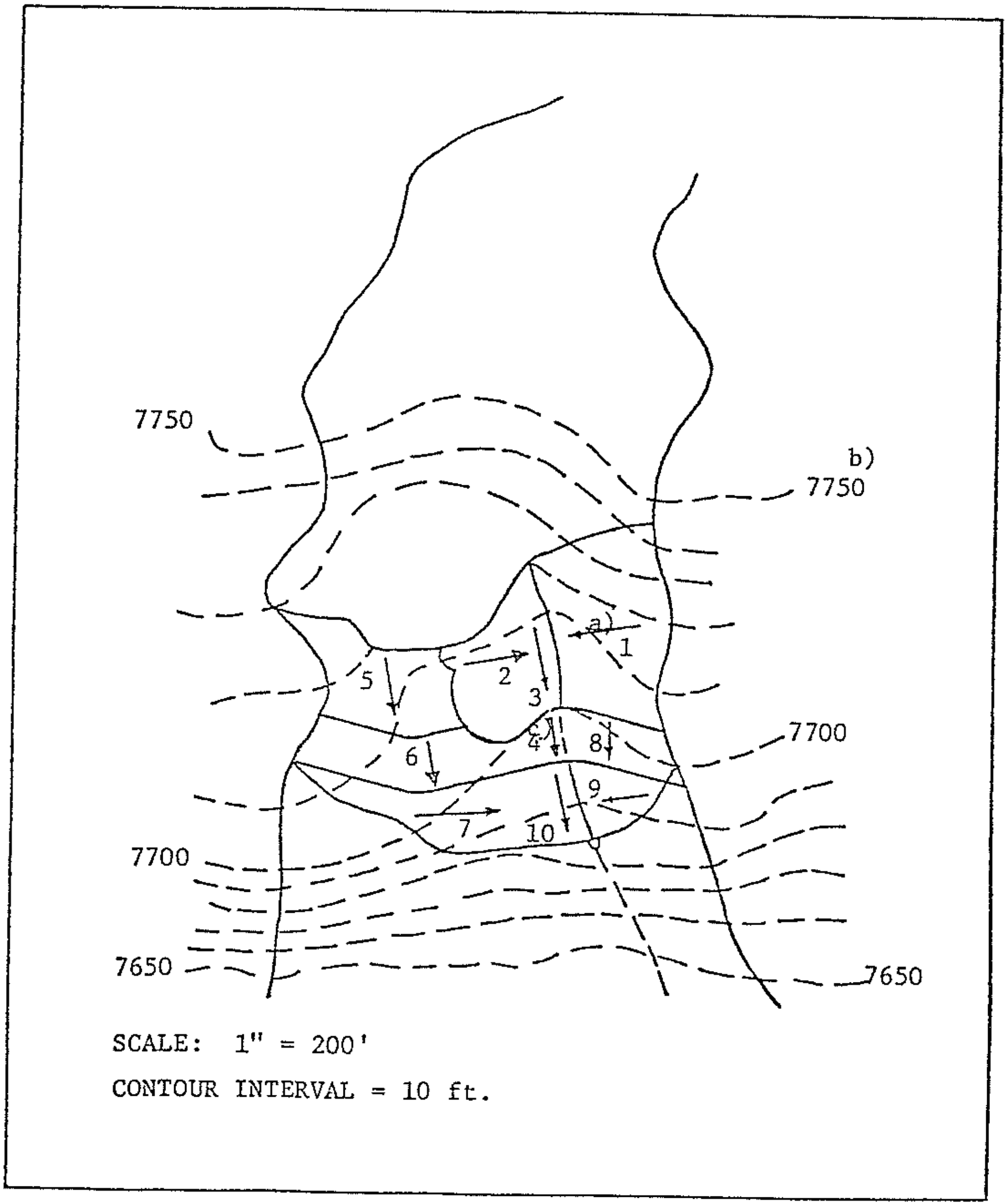

Figure 6. Ponderosa Pines site Pond watershed with road.

a) The arrows indicate the direction of flow.
b) The horizontal dotted lines represent the contour lines.
c) The vertical dotted lines (channel 4) represent a culvert.

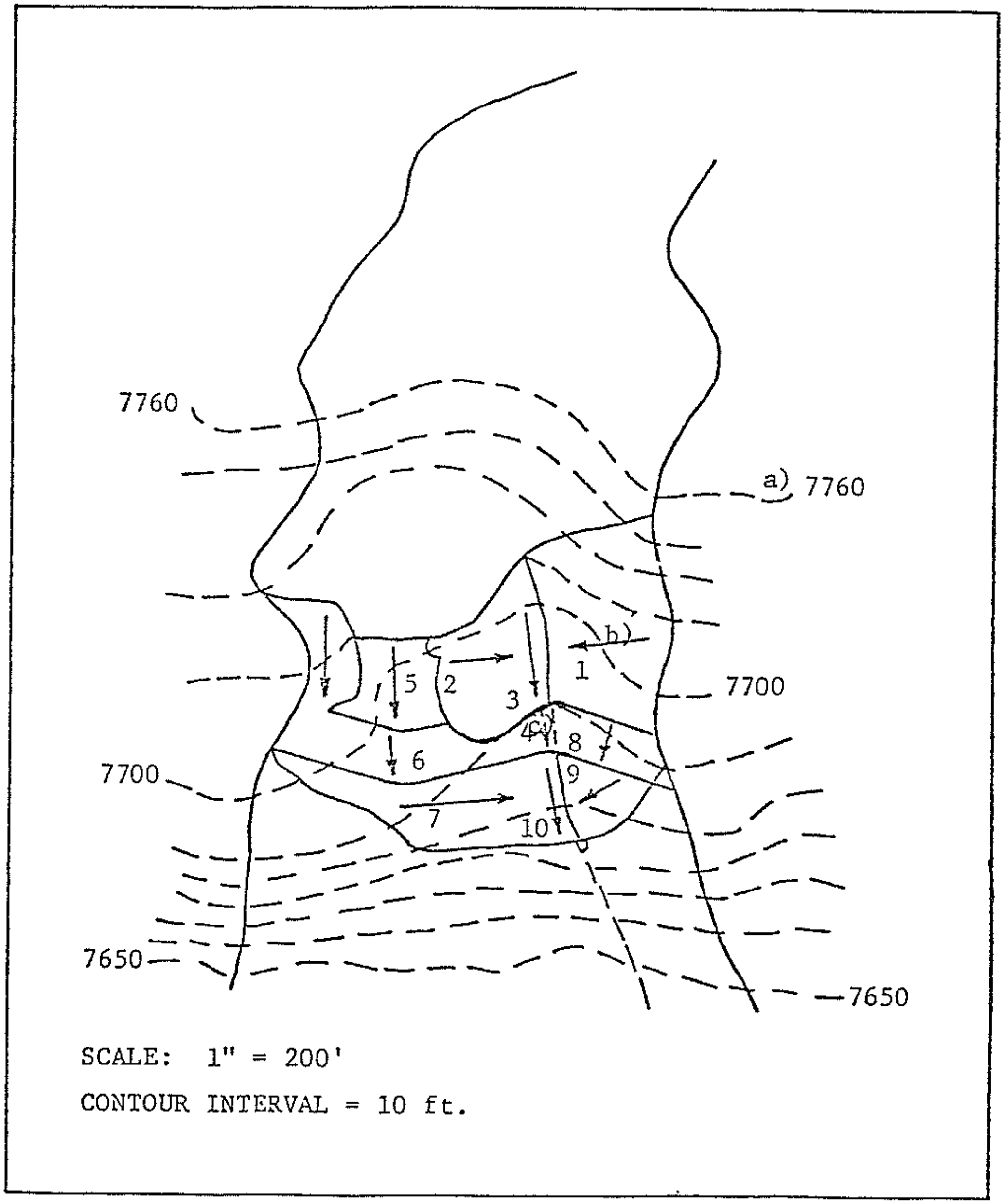

Figure 7. Ponderosa Pines site Pond watershed with road and parking lot.

a) The arrows indicate the direction of flow.
b) The horizontal dotted lines represent the contour lines.
c) The vertical dotted lines (channel 4) represent a culvert.

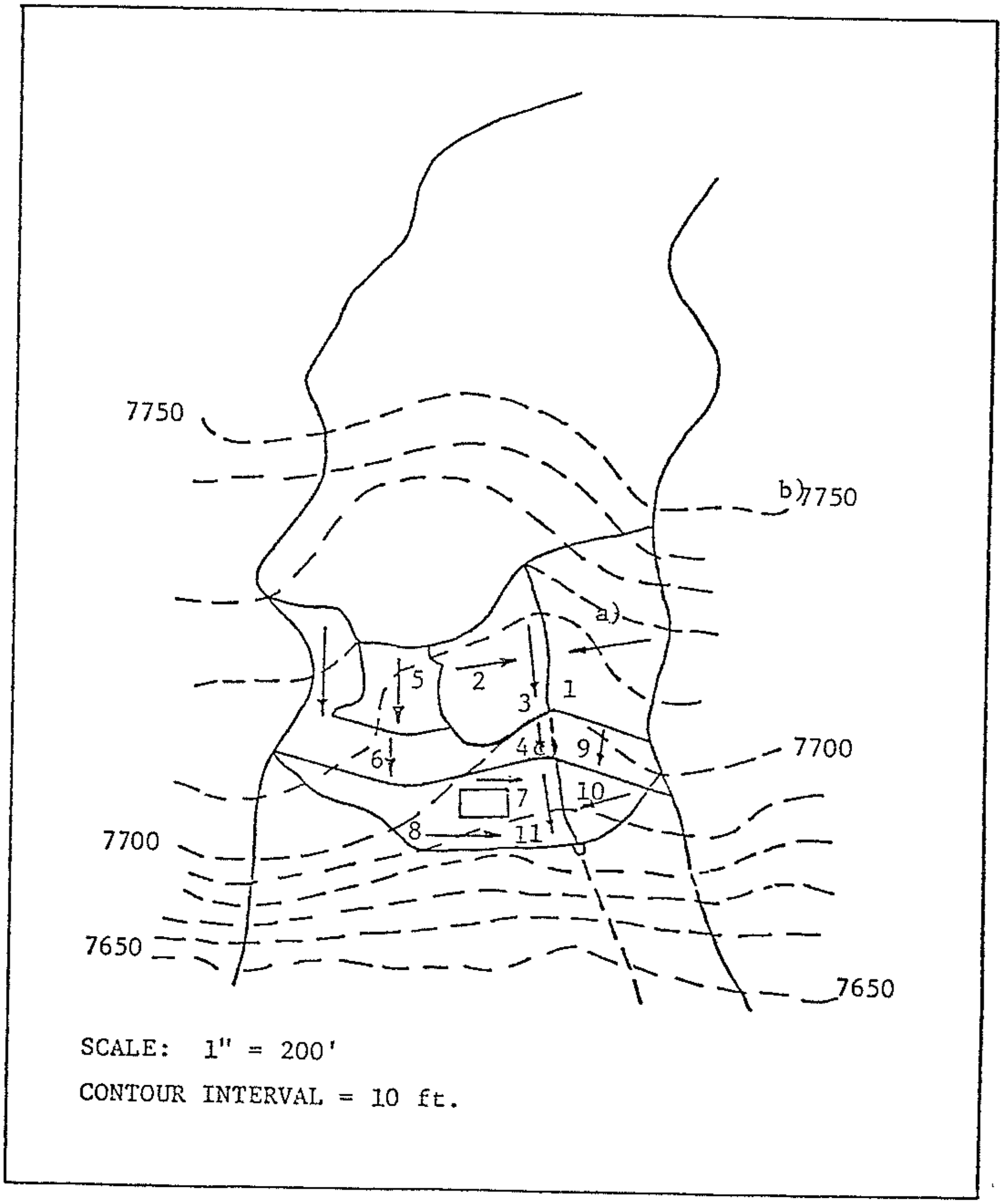

Figure 8. Ponderosa Pines site Pond watershed, development at the time of measurement.

a) The arrows indicate the direction of flow.
b) The horizontal dotted lines represent the contour lines.
c) The vertical dotted lines (channel 4) represent a culvert.
d) The box (plane 7) represents a house.

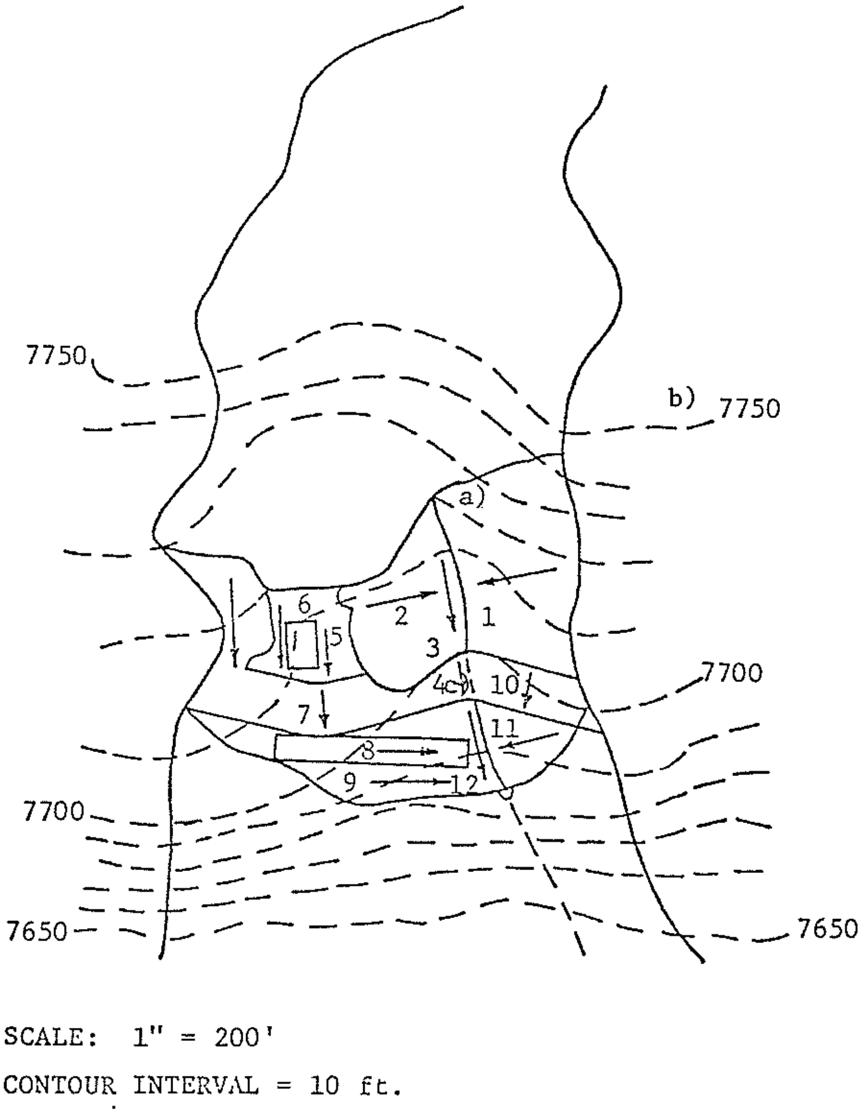

Figure 9. Ponderosa Pines site Pond watershed assuming full development.

a) The arrows indicate the direction of flow.
b) The horizontal dotted lines represent the contour lines.
c) The vertical dotted lines (channel 4) represent a culvert.
d) The boxes (planes 5 and 8) represent houses.

Tables 6 and 7 show the predicted and observed values for the different calibrations. Table 6 is a comparison between predicted and observed runoff volume in cubic feet, while table 7 is a comparison between predicted and observed runoff peaks in cubic feet per second. The units are those used by the Kingen 75 simulation model. Both tables show that the first calibration (Fmin = 0.1055) best simulated the actual runoff volumes and peaks except for the 08/14/80 hydrograph. For all practical purposes 2.35, 2.14 and 1.23 cubic feet (table 6) of volume are essentially equal to zero. Note that the 08/14/80 hydrograph is for a different year in both tables and reflects a shift in the value for optimum Fmin hydrograph. Evidently this difference is due to the fact that the first four hydrograph readings correspond to the summer of 1979 period, while the fifth hydrograph corresponds to the summer of 1980 period. Thus, the 08/14/80 hydrograph refers to a different stage of development. The summer of 1979 period corresponds to Simulation 4.

The chronology of activities for the Ponderosa Pines development shows that all the main roads had been resurfaced with shale by June 5, 1980. The first heavy rain (4.2 in.) occurred August 14, 1980. This may be the reason for the shift in preferred Fmin between the predicted hydrographs for the summer of 1979 and the one for the summer of 1980.

Table 8 shows the infiltration parameters with their respective definitions and values used in the calibration and simulation. Table 9 presents a summary of runoff volume and peak results for the different simulated stages of development.

Table 6. Sensitivity analysis: comparison between predicted and observed runoff volume.

	Fmin. (ipm)[a] Calibration	Runoff Volume (CF)			
		06/06/79 Hydrograph		07/23/79 Hydrograph	
		Observed	Predicted	Observed	Predicted
ARF[b]		0.90 in.		0.34 in.	
RFI[c]		0.54 iph.		0.1925 iph.	
	0.1055[d]	160.47	159.35	2.35	0.00
	0.0723	160.47	1988.06	2.35	0.00
	0.0717	160.47	2021.44	2.35	0.00
	0.04469	160.47	3936.41	2.35	13.77
		09/15/79 Hydrograph		09/21/79[e] Hydrograph	
		Observed	Predicted	Observed	Predicted
ARF[b]		0.55 in.		0.30 in.	
RFI[c]		0.3113 iph		0.45 & 0.30 iph.	
	0.1055	2.14	0.00	1.23	0.00
	0.0723[d]	2.14	0.00	1.23	0.00
	0.0717	2.14	24.83	1.23	0.00
	0.04469	2.14	1096.68	1.23	278.31
		08/14/80[f] Hydrograph			
		Observed	Predicted		
ARF[b]		0.95 in.			
RFI[c]		0.3067, 0.1440, 0.3067 & 0.24 iph.			
	0.1055[d]	92.4	0.00		
	0.0723	92.4	85.29		
	0.0717	92.4	242.32		
	0.04469	92.4	1418.54		

[a] Infiltration rate in inches per minutes.

[b] Accumulated rainfall in inches.

[c] Rainfall intensity in inches per hours.

[d] Infiltration rate that should be used.

[e] This is a double peak hydrograph.

[f] This hydrograph has four peaks.

Table 7. Sensitivity analysis: comparison between predicted and observed runoff peaks.

	Fmin. (ipm)[a] Calibration	Runoff Peaks (Max. CFS			
		06/06/79 Hydrograph		07/23/79 Hydrograph	
		Observed	Predicted	Observed	Predicted
ARF[b]		0.90 in.		0.34 in.	
RFI[c]		0.54 iph.		0.1925 iph.	
	0.1055	0.0645	0.09122	0.00245	0.00
	0.1723[d]	0.0645	0.66555	0.00245	0.00
	0.0717	0.0643	0.67453	0.00245	0.00
	0.04469	0.0645	0.92753	0.00745	0.01392
		09/15/79 Hydrograph		09/21/79[e] Hydrograph	
		Observed	Predicted	Observed	Predicted
ARF[b]		0.55 in.		0.30 in.	
RFI[c]		0.3113 iph.		0.45 7 0.30 iph.	
	0.1055[d]	0.00166	0.00	0.00081 & 0.00069	0.00
	0.1723	0.00166	0.00	0.00081 & 0.00069	0.00
	0.0171	0.00166	0.02763	0.00081 & 0.00069	0.00
	0.04469	0.00166	0.33214	0.00081 & 0.00069	0.04312 & 0.20844
		08/14/80[f] Hydrograph			
		Observed	Predicted		
AFR[b]		0.95 in.			
RFI[c]		0.3067, 0.1440, 0.3067, & 0.2400 iph.			
	0.1055[d]	0.03053, 0.01073, 0.02388 & 0.017434	0.00		
	0.1723	0.03053, 0.01073, 0.02388 & 0.01734	0.04864		
	0.0171	0.03053, 0.01073, 0.02388 & 0.01734	0.11028		
	0.04469	0.03053, 0.01073, 0.02388 & 0.01734	0.25921, 0.14275, 0.12471 & 0.08439		

[a] Infiltration rate in inches per minutes.

[b] Accumulated rainfall in inches.

[c] Rainfall intensity in inches per hours.

[d] Infiltration rate that should be used.

[e] This is a double peak hydrograph.

[f] This is a hydrograph with four peaks.

The following discussion and figures 5 through 8 refer to Pond site in Ponderosa Pines. Figure 5 represents Pond site watershed assuming no development; this watershed was divided into five pervious planes (planes 1 and 2) and a pervious trapezoidal channel (channel 3). The predicted runoff volume and runoff peak for this stage of development was zero.

Figure 6 represents this site with the road only. This watershed was divided into five pervious planes (planes 1, 2, 5, 7 and 9), two impervious planes (plane 6 and 8), two pervious channels (channels 3 and 10) and one impervious channel (culvert 4). The predicted runoff volume and runoff peak for this stage of development were 159.70 cubic feet and 0.09144 cubic feet per second, respectively.

Figure 7 represents the site with the road and parking lot. This watershed was divided into five pervious planes (1, 2, 5, 7 and 9), two impervious planes (plane 6, which includes a road and parking lot, and plane 8), two pervious channels (channels 3 and 10) and one impervious channel (culvert 4). The predicted runoff volume and runoff peak for this stage of development were 159.35 cubic feet and 0.09122 cubic feet per second respectively.

Figure 8 represents development at Pond site at the time of measurement. This watershed was divided into five pervious planes (1, 2, 5, 8 and 10), three impervious planes (plane 6 which included the road and parking lot, plane 7 which is a house and plane 9), two pervious channels (channel 3 and 11) and one impervious channel (culvert 4). The predicted runoff volume and runoff peak for this particular stage of development were 159.35 cubic feet and 0.09122 cubic feet per second.

Table 8. Infiltration parameters used in Ponderosa Pines site Pond simulation.

Parameter	Definition of Parameter	Value of Parameter
AL	Exponent parameter for decay curve	0.51
B	Ponding time parameter	0.80
C	Infiltration scaling parameter	8417
SI	Initial volumetric relative water content	0.30
SMAX	Maximum volumetric content under inhibition	0.90
ROC	Volumetric relative rock content	0.40

Table 9. Comparison of runoff volume and values for different stages of development at Ponderosa Pines site Pond watershed.

Stages of Development	Runoff Volume, CF		Runoff Peaks, CFS	
	Observed	Predicted	Observed	Predicted
No development	--	0.00	--	0.00
Road only	--	159.70	--	0.09144
Road and parking lot	--	159.35	--	0.09122
Development at the time of measurement	160.47	159.35	0.0645	0.09122
Full development	--	536.73	--	0.44408

The observed values are recorded as 160.47 cubic feet and 0.0645 cubic feet per second, respectively. According to the predicted and observed values, the simulation model predicts well.

Finally, figure 9 represents Pond site assuming full development. This watershed has been broken down into five pervious planes (planes 1, 2, 6, 9 and 11), four impervious planes (plane 5 which is a house, plane 7 which includes the road and parking lot, plane 8 which represents the area of four houses, and plane 10), two pervious channels (channels 3 and 12) and an impervious channel (culvert 4). The predicted runoff volume and runoff peak were 536.73 cubic feet and 0.44408 cubic feet per second, respectively.

Table 9 shows that after an initial level of development (road only), the predicted runoff volume and peak stayed constant up to the level of development at the time of measurement. At full development the predicted runoff increased approximately 237 percent in relation to the development at the time of measurement.

Regression Analysis

The third hypothesis of this study was tested using regression analysis. Regression analysis was used to measure the relationship between the different dependent variables (% TDS, COD, CA^{++}, $PO_4^{=}$, NH_4^{+}) and the independent variable, accumulated rainfall (ARF). ARF is the rainfall depth for every particular event. Dummy variables were used to account for the year the data was collected. The dummy variable takes the value of "1" when a particular year of interest is present, and "0" when the particular year is not present. All results were summarized in tables 10 through 15. Table 10 shows the possible regressions of percent total dissolved solids (% TDS) for the different sites. The general model used was the following:

$$\% \text{ TDS} = \beta_0 + \beta_1 \text{ARF} + \beta_2 \text{DUM74} + \beta_3 \text{DUM75} + \beta_4 \text{DUM79} + \varepsilon_i ,$$

or a modification, depending on the year of the data. For instance, when the data available were only from 1979, the model used was:

$$\% \text{ TDS} = \beta_0 + \beta_1 \text{ARF} + \varepsilon_i$$

For example from table 10:

Control:

$$\% \text{ TDS} = \underset{(-1.35)}{-0.15387} + \underset{(7.16)}{0.00820\text{ARF}}$$

R-square = 0.90

F-value = 51.31

PR > F = 0.0004

The numbers in parentheses indicate the <u>t</u>-values.

The signs for the intercept and the accumulated rainfall within each year's data are as expected. The intercept should be negative to reflect the fact that runoff, and hence, dissolved solids are not exhibited until rainfall has accumulated to produce runoff.

The coefficient of determination tells us that 90 percent of the variation which occurs in percent total dissolved solids is explained by the intercept and accumulated rainfall variable. Therefore, there remains after the direct effect of the size of the rainstorm, approximately 10 percent of the variation in percent total dissolved solids to be explained by other factors.

Table 10. Percent total dissolved solids (% TDS): estimated variable coefficients and comparison among the different sites.

Site	R^2	F-value	Intercept	ARF	DUM74	DUM75	DUM79
Control	0.90	51.31	-0.15387	0.00820	--	--	--
			(-1.33)	(7.16)			
	0.99	121.43	-0.12532	0.00543	0.32056	0.56871	--
			(-2.55)	(5.76)	(1.91)	(5.18)	
	0.99	121.43	0.19525	0.00543	--	0.24815	-0.32056
			(1.01)	(5.76)		(2.16)	(-1.19)
	0.92	27.35	-0.19415	0.00925	-0.31712	--	--
			(-1.66)	(6.32)	(-1.12)		
	0.98	117.92	-0.16275	0.00695	--	0.41504	--
			(-2.93)	(11.15)		(4.50)	
	0.98	103.80	0.50527	0.00444	--	--	0.59616
			(2.98)	(4.09)			(-4.15)
101	0.14	1.93	2.63599	0.03635	--	--	--
			(1.19)	(1.39)			
	0.79	12.89	1.85142	-0.01847	10.29017	10.23687	--
			(1.54)	(-1.05)	(3.92)	(5.39)	
	0.79	12.89	12.08829	-0.01847	0.05330	--	-10.23687
			(5.79)	(-1.05)	(0.02)		(-5.39)
	0.79	12.89	12.14159	-0.01847	--	-0.05330	-10.29017
			(4.17)	(-1.05)		(-0.02)	(-3.92)
	0.20	1.36	2.83837	0.02459	4.00766	--	--
			(1.27)	(0.84)	(0.90)		
	0.48	5.05	1.75321	0.01970	--	6.92898	--
			(0.96)	(0.89)		(2.68)	
	0.79	21.27	12.09690	-0.01838	--	--	-10.24911
			(6.19)	(-1.13)			(-5.93)
Pond	0.71	4.95	-0.03682	0.00560	--	--	--
			(-0.30)	(2.23)			
Pond and 101 Aggregated	0.14	3.13	1.40084	0.04180	--	--	--
			(0.76)	(1.77)			
	0.82	21.62	1.55417	-0.01778	10.50224	10.47231	--
			(1.69)	(-1.21)	(4.84)	(6.81)	
	0.82	21.62	12.02480	-0.01778	0.02993	--	-10.47231
			(6.81)	(-1.21)	(0.01)		(-6.91)
	0.82	21.62	12.05641	-0.01778	--	-0.02993	-10.50224
			(4.89)	(-1.21)		(-0.01)	(-4.84)
	0.23	2.30	1.73704	0.02774	4.772066	--	--
			(0.94)	(1.06)	(1.18)		
	0.53	8.31	0.97150	0.02137	--	7.56142	--
			(0.68)	(1.10)		(3.38)	
	0.82	34.75	12.031155	-0.01773	--	--	-10.47441
			(7.20)	(-1.29)			(-7.46)

Table 11. Percent total dissolved solids (% TDS): estimated variable coefficients and comparison among the selected equations of the different sites.

	Sites			
	Control	101	Pond	Pond and 101 Aggregated
R^2	0.99	0.79	0.71	0.82
F-value	121.43	21.27	4.95	34.75
Intercept	0.44340 (3.36)	12.09690 (6.19)	-0.03682 (-0.30)	12.03155 (7.20)
ARF	0.00543 (5.76)	-0.01838 (-1.13)	0.00560 (2.23)	-0.01773 (-1.29)
DUM74	-0.24815 (-2.16)	--	--	--
DUM75	--	--	--	--
DUM79	-0.56871 (-5.18)	-10.24911 (-5.93)	--	-10.47941 (-7.46)

Table 12. Chemical oxygen demand (COD): estimated variable coefficients and comparison among the different sites.

	Sites			
	Control	101	Pond	Pond and 101 Aggregated
R^2	0.020	0.053	0.338	0.091
F-value	0.06	0.33	1.02	1.00
Intercept	115.63533 (0.45)	693.03277 (1.24)	1247.15232 (1.64)	827.02662 (1.97)
ARF	1.64060 (0.25)	-7.26728 (-0.58)	-15.90894 (-1.01)	-9.16497 (-1.00)

Table 13. Calcium (CA^{++}): estimated variable coefficients and comparison among the different sites.

	Sites			
	Control	101	Pond	Pond and 101 Aggregated
R^2	0.156	0.022	0.066	0.018
F-value	0.55	0.18	0.21	0.24
Intercept	19.93786 (4.31)	80.87245 (8.02)	87.04744 (12.18)	82.61402 (11.41)
ARF	0.08850 (0.74)	-0.09730 (-0.42)	-0.07361 (-0.46)	-0.08134 (-0.49)

Table 14. Orthophosphate ($PO_4^{=}$): estimated variable coefficients and comparison among the different sites.

	Sites			
	Control	101	Pond	Pond and 101 Aggregated
R^2	0.234	0.399	0.007	0.095
F-value	0.61	5.32	0.02	1.37
Intercept	0.12922 (0.22)	0.04026 (0.89)	0.21990 (1.40)	0.09491 (1.65)
ARF	0.01059 (0.78)	0.00241 (2.31)	-0.00053 (-0.15)	0.00153 (1.17)

Table 15. Ammonia nitrogen (NH_4^+): estimated variable coefficients and comparison among the different sites.

	Sites			
	Control	101	Pond	Pond and 101 Aggregated
R^2	0.087	0.028	0.144	0.048
F-value	0.19	0.23	0.50	0.66
Intercept	2.23063 (1.87)	0.97277 (3.20)	1.27233 (2.86)	1.06262 (4.49)
ARF	-0.01209 (-0.44)	-0.00334 (-0.48)	-0.00706 (-0.71)	-0.00436 (-0.81)

Table 11 shows the equations with the respective estimated coefficients chosen from table 10 for percent total dissolved solids for the different sites. The selection criteria were R-square and significant t-values.

The selected equations are described below for each site:

1. $$\%\ \text{TDS} = \underset{(3.36)}{0.44340} + \underset{(5.76)}{0.00543\text{ARF}} - \underset{(-2.16)}{0.24815\text{DUM74}} - \underset{(-5.18)}{0.56871\text{DUM79}}$$

   R-square = 0.99

   F-value = 121.43

   PR > F = 0.0002

The sign is as expected for ARF, but not for the intercept. The intercept effect is evidently due to variation between years since the sign of the intercept is always positive when the year dummy variables are included. This is a reflection of the self-healing of the disturbed site occurring between 1974 and 1979 (see figure 2).

The coefficient of determination tells us that 99 percent of the variation in percent total dissolved solids is explained by the model given above. However, there remains after the direct effect of the size of the rainstorm, approximately 86 percent of the variation in percent total dissolved solids (% TDS) to be explained by other factors including the construction activity.

$$\%\ \text{TDS} = \underset{(6.19)}{12.09690} - \underset{(-1.13)}{0.01838\text{ARF}} - \underset{(-5.93)}{10.24911\text{DUM79}}$$

R-square = 0.79

F-value = 21.27

PR > F = 0.0002

The coefficient of determination tells us that 79 percent of the variation in percent total dissolved solids (% TDS) is explained by the model given above. However, approximately 21 percent of the variation in percent total dissolved solids remains to be explained by other factors.

2. Pond:

$$\% \text{ TDS} = \underset{(-0.30)}{-0.03682} + \underset{(2.23)}{0.00560\text{ARF}}$$

R-square = 0.71

F-value = 4.95

PR > F = 0.156

Here, 71 percent of the variation in percent total dissolved solids (% TDS) is explained by accumulated rainfall (ARF), while the other 29 percent remains to be explained by other factors, including the construction activity.

$$\% \text{ TDS} = \underset{(7.20)}{12.03155} - \underset{(-1.29)}{0.01773\text{ARF}} - \underset{(-7.46)}{10.47941\text{DUM79}}$$

R-square = 0.82

F-value = 35.75

PR > F = 0.0001

This particular model explains 82 percent of the variation in percent total dissolved solids, while 18 percent of the variation remains to be explained by other factors.

In the same fashion, table 8 gives the estimated coefficients for the following model in the different sites:

$$\text{COD} = \beta_0 + \beta_1\text{ARF} + \varepsilon_1$$

Tables 9, 10, 11 represent the same kind of analysis but for calcium, orthophosphate and ammonia nitrogen, respectively. The models used were the following:

$$\text{CA}^{++} = \beta_0 + \beta_1\text{ARF} + \varepsilon_1$$

$$PO_4^{=} = \beta_0 + \beta_1 ARF + \varepsilon_i$$

$$NH_4^{+} = \beta_0 + \beta_1 ARF + \varepsilon_i$$

The results presented in tables 8 through 11 indicate that most of the variations in the expected chemical oxygen demand (COD), calcium (CA^{++}), orthophosphates ($PO_4^{=}$) and ammonia nitrogen (NH_4^{+}) are explained by some factors other than the accumulated rainfall (ARF). The coefficient of determination for the last four models was extremely low.

SECOND-HOME DEVELOPMENT PREDICTION METHODOLOGY IN CLOUDCROFT, NEW MEXICO

Hypothesis and Objective

The objective of this portion of the study was to develop an econometric model that would predict second-home development for the region of Cloudcroft, New Mexico.

The hypothesis of the study was that most of the variation in the endogeneous variable second-home development (Y) is explained by the exogeneous variables, land transactions (X_1), interest rates (X_2), deflated lag price of crude oil (X_3), selling price of houses (X_5) property taxes (X_6), population of certain Texas cities (X_6), per capita income of certain Texas cities (X_7), gasoline prices (X_8) and a dummy variable (X_4) to account for the oil embargo.

Structural Definition

The study began with the following theoretical structural form:

$$Y = f(X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8) \text{ or}$$

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \mu$$

This equation or structural form is suggested by economic theory and the stochastic term has been added because of the behavioral nature of these relationships. Theory suggests to us a direct relationship between demand for second home and land transaction. Economic theory suggests an inverse relationship between demand for second home and interest rate. In other words, if interest rate was to increase, demand for second home would decrease. Economic theory also suggests an inverse relationship between demand for second home and its own price, price of crude oil and price of gasoline. This means that if the price for a second home increases, the demand for the secondhome will decrease. The same would be expected to be true if prices of crude oil and/or gasoline were to increase. Population and per capita income of certain Texas cities would be expected to be directly related to demand for second homes. That is, if the population and income of certain Texas cities were to increase, the demand for second home would be expected to increase. The population and income of certain Texas cities would be used because most of the owners of second homes in Cloudcroft, New Mexico, are from certain Texas cities along with a few from New Mexico. Property taxes would be expected to be inversely related to the demand for second homes. In other words, if property taxes were to increase (or were very high), demand for second homes would decrease.

Because of a time constraint, some of the variables were not quantified. The following variables were quantified:

Residential building permits (Y): This variable was used as the demand for second home, i.e. this was used as the dependent variable.

The data was obtained from the General Construction Bureau, Bataan Memorial Building, Room 202, Santa Fe, New Mexico 82503. This data is available from 1968 to 1979 for Cloudcroft, New Mexico.

Land transaction (X_1): This variable was quantified using the records from the Alamogordo Court House, New Mexico. The records used were from the grantor to the grantee.

Interest rates (X_2): This data was obtained using the 1977 Agricultural Statistics for the year 1968 through 1976 and the 1980 Agricultural Statistics for the years 1977 through 1979, pages 488 and 483, respectively.

Lag prices of crude oil (LPCOIL): This data was obtained from three sources: (1) the 1979 Agricultural Statistics for the years 1971 through 1973, page 488; (2) the Historical Statistics of the U.S. Colonial Times to 1970 I2958 for the years 1968 through 1970; and (3) the Monthly Energy Review, December 1978, page 68 and August 1981, page 76 for the years 1974 through 1979. By deflating this variable inflation was taken into account. This variable was also lagged one year assuming that people based their decisions on last year prices. The units used are dollars per barrel.

Consumer price index for private transportation (CPI-TP): The data for this variable was obtained from the 1979 Statistical Abstract, page 483. This variable was also lagged and used to deflate the lag prices of crude oil. All of this data has been provided in table 16.

Of all the models which were studied, the following ones yielded the highest coefficient of determinations (R^2) and highest t-values:

1. $Y = \beta_1 X_1 + \beta_2 X_{133} + \mu$

   $X_{133} = X_1 \cdot X_{33}$

   $X_{33} = X_3 \cdot X_3$

2. $Y = \beta_1 X_1 + \mu$

Table 16. Data for use in the prediction of second-home development.

n	Year	Variables					
		Y	X_1	X_2	LPCOIL	CPI-TP	X_3
1	1968	21	199	641	292	100.0	2.92
2	1969	18	200	7.23	2.94	103.00	2.85
3	1970	26	191	8.46	3.09	106.50	2.90
4	1971	28	170	6.33	3.18	111.10	2.86
5	1972	45	281	6.00	3.39	116.60	2.91
6	1973	34	220	7.31	3.39	117.50	2.89
7	1974	42	189	8.78	3.89	121.50	3.20
8	1975	11	205	8.14	6.87	136.60	5.03
9	1976	27	191	7.36	7.67	149.80	5.12
10	1977	27	285	6.94	8.19	164.60	4.98
11	1978	39	338	8.06	8.57	176.60	4.85
12	1979	38	345	10.18	9.00	185.00	4.86

Sources: General Construction Bureau, Number of Residential Permits in Cloudcroft, New Mexico. Bataan Memorial Building, Room 202, Santa Fe, New Mexico 82503.

United States Department of Agriculture, Agricultural Statistics, 1977, 1979, 1980, pp. 488, 483, and 483.

Alamogordo Court House, Land Transaction in Cloudcroft, New Mexico.

Monthly Energy Review, December 1978, p. 68 and August 1981, p. 76.

Historical Statistic of the U.S. Colonial Times to 1970, I2958.

Table 17. Projecting second-home development: estimated variable coefficients and comparison among the selected equations.

Equation in Figure Number	R^2 %	F-value	Variables					
			X_1	X_2	X_3	X_4	X_{33}[a]	X_{133}[b]
1	94.57	87.00	0.16915 (7.26)					-0.002596 (-2.31)
2	92.10	128.19	0.12405 (11.32)					
3	90.82	49.46			17.51633 (4.89)		-2.38252 (-2.99)	
4	92.20	35.48			18.1492 (5.26)	11.03631 (1.26)	-2.96077 (-3.29)	
A	94.14	48.22	0.12877 (2.62)	2.37326 (1.44)	-4.87748 (-1.62)			
B	89.52	93.91		3.8465 (9.69)				
C	82.62	52.29			7.25647 (7.23)			
D	94.54	34.60	0.13545 (2.65)	2.49923 (1.50)	-6.50669 (-1.73)	5.31546 (0.76)		

[a] $X_{33} = X_3 \cdot X_3$

[b] $X_{133} = X_1 \cdot X_{33}$

3. $Y = \beta_1 X_3 + \beta_2 X_{33} + \mu$

$X_{33} = X_3 \cdot X_3$

4. $Y = \beta_1 X_3 + B_2 X_{33} + \beta_3 X_4$

$X_{33} = X_3 \cdot X_3$

Estimation of parameter and interpretations: The estimated coefficients for the best equations are summarized in table 17.

Model 1. $\hat{Y} = \underset{(7.26)}{0.16915X_1} - \underset{(-2.31)}{0.002596X_{133}}$

R-square = 94.57%

This model as a whole has predictive ability at the 0.01 percent significance level. Also, almost 95 percent of the variation in the dependent variable is explained by the given model.

The signs indicate the direction of the relationship. For instance, if X_1 (land transaction) increases by one unit, $\hat{Y}$ (demand for second home) increases by 0.16915 units. Now, if X_{133} (which is the product between land transaction and the square of the deflated lagged price of crude oil) increases by one unit, $\hat{Y}$ decreases by 0.002596 units.

Model 2. $\hat{Y} = \underset{(11.32)}{0.12405X_1}$

R-square 92.10%

The model as a whole is significant at the 0.01 percent significance level. This model explains 92 percent of the variation in the dependent variable. X_1 is very significant. This is the best one-variable equation.

Model 3. $\hat{Y} = \underset{(4.89)}{17.51633X_3} - \underset{(-2.99)}{2.38252X_{33}}$

R-square = 90.82%

This particular model has predictive potential at the 0.01 significance level. Even though the variables are statistically significant and the model explains almost 91 percent of the variation in the dependent variables, most of the residuals are very large.

Model 4. $\hat{Y} = \underset{(5.26)}{18.149X_3} - \underset{(-3.29)}{2.96077X_{33}} + \underset{(1.26)}{11.03631X_4}$

R-square = 92.20%

This last model has predictive potential at the 0.01 percent significance level. The model also explains 92 percent of the variation in the dependent variable. Model 4 has one *t*-value that is not significant at the .01 level, however, this model uses variables that have a more long range effect including the consumer price index for private transportation.

A graphical comparison of the performance of these models is given in figures 10 through 12.

Description of Second-Home Development

According to a confidential questionnaire carried out as a part of this study, 81 percent of the lot owners will develop their lot, 23.8 percent will use the property primarily for permanent home, 28.5 percent for vacation home, 19.04 percent for investment only, 28.6 percent for vacation home and investment, 94.1 percent of lot owners developed water systems and 5.9 percent of lot owners had to drill a well. A copy of the questionnaire and summary of results is presented in Appendix B. Thirty-eight questionnaires were mailed out and 25 were returned which

Figure 10. Predicted (– –) vs. observed (——) values for second-home development at Cloudcroft, New Mexico. Model 1. ($\hat{Y}$ = 0.16915X1 - 0.002596X133)

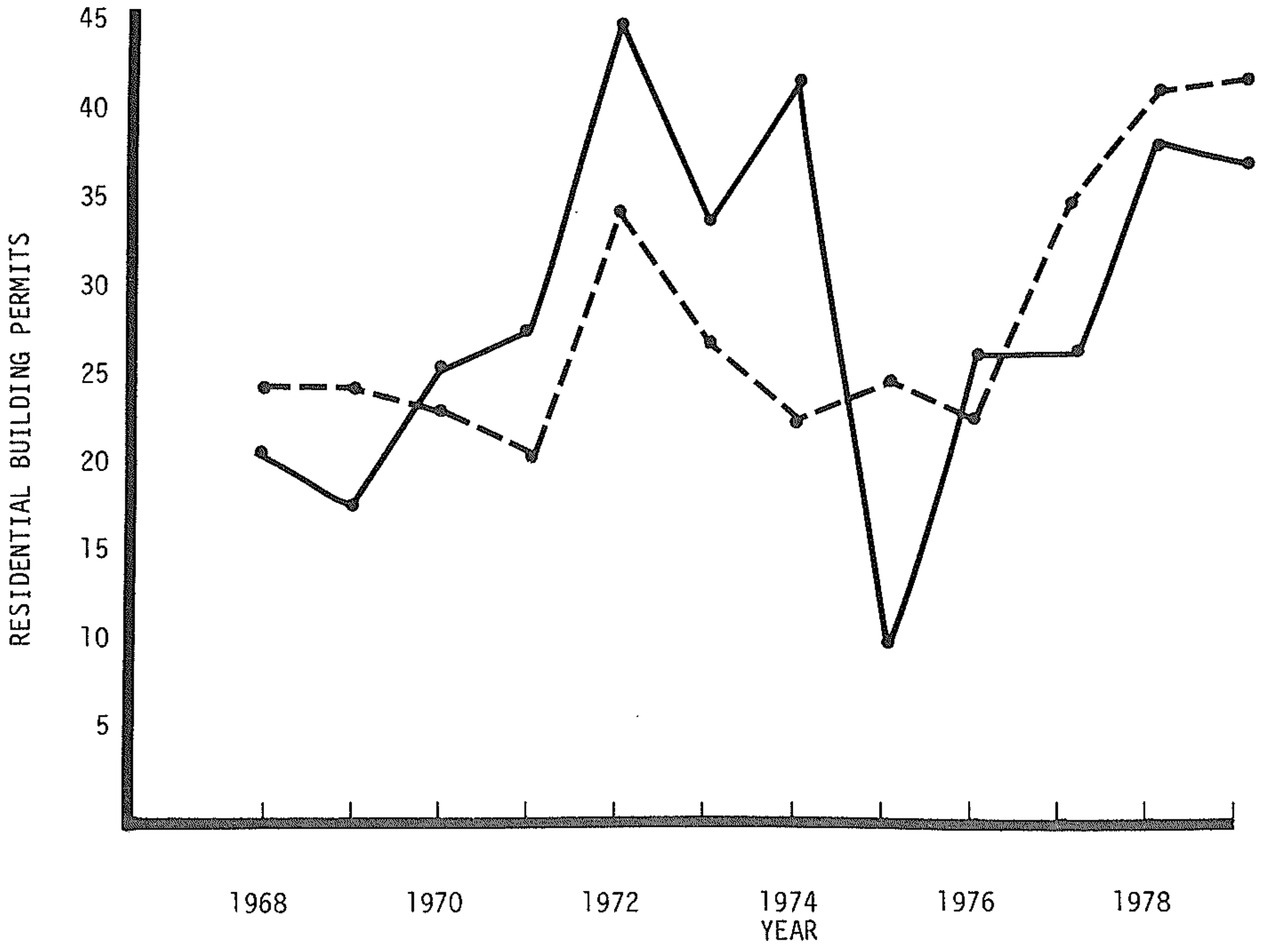

Figure 11. Predicted (— —) vs. observed (——) values for second-home development at Cloudcroft, New Mexico. Model 2. ($\hat{Y} = 0.12405X1$)

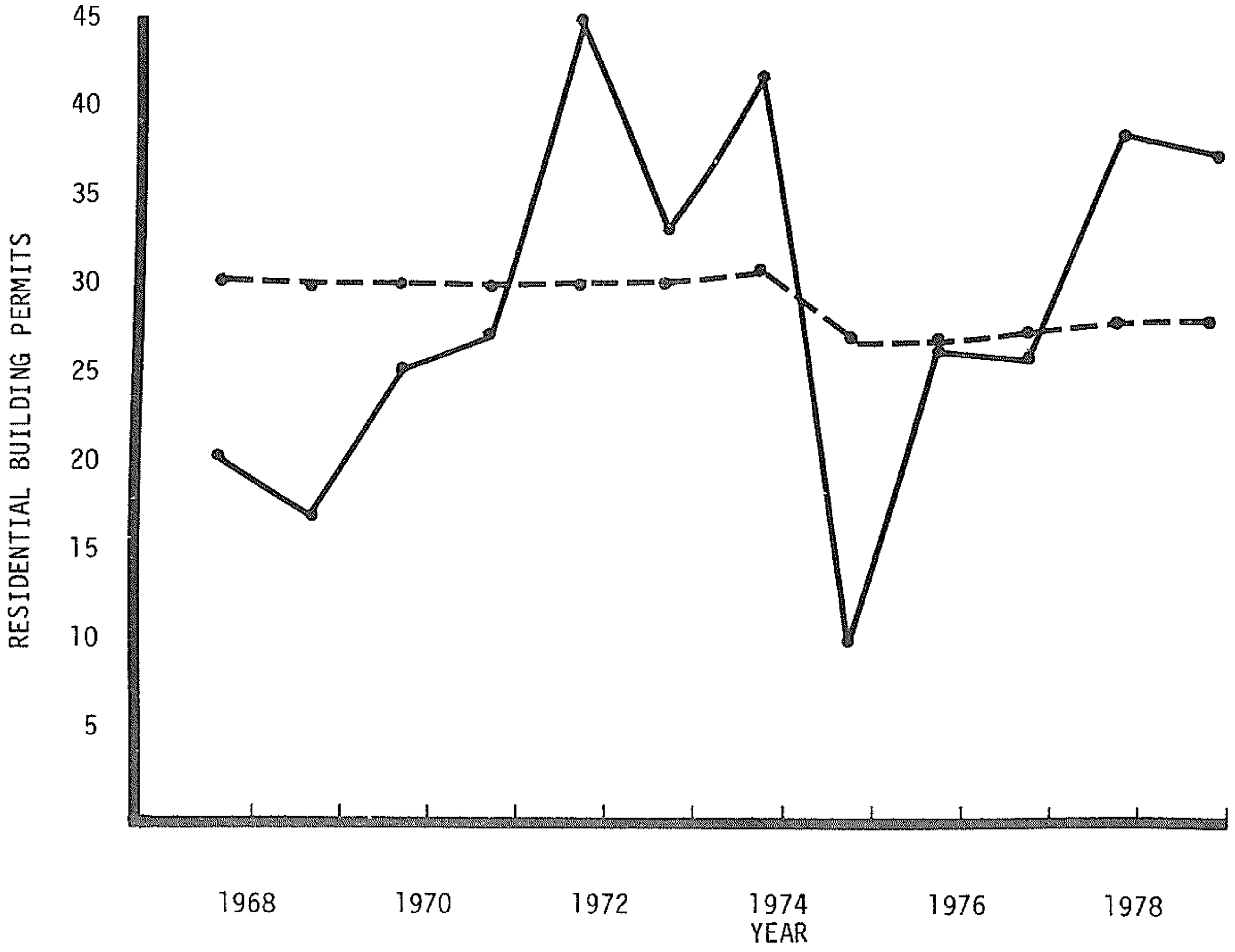

Figure 12. Predicted (— —) vs. observed (——) values for second-home development at Cloudcroft, New Mexico. Model 3. ($\hat{Y} = 17.51633X3 - 2.38252X33$)

represents 55.26 percent response. This was done for the Ponderosa Pine subdivisions of Cloudcroft, New Mexico.

CONCLUSIONS

This study was initiated to determine the effects of construction activities on selected water quality parameters for small forested watersheds. The percent total dissolved solids was the only water quality parameter consistantly showing a significant increase between the control site and perturbation activity. This result indicates that the percent total dissolved solids is a key parameter when monitoring construction impacts. This test also determined that a presumed low-activity level construction site, as at Site 101, can contribute more waste than active construction as at site Pond. Site 101 was under road construction and Pond had road construction completed and power lines and trenches for utilities were being placed in the area. The figures from this experiment indicate that even low-level activity on an environmentally fragile site can have harmful effects, lasting over a long period of time, while heavy activity can be tolerated in more robust acres.

Sediment traps should be deliberately installed by developers to mitigate the problem of increased total dissolved solids as has been suggested by Khanna and others (13). An additional helpful practice is the timely planting of erosion control grasses and plants.

The infiltration rate (Fmin.) was proven to be the most sensitive factor tested while using the Kingen 75 simulation model. The model was calibrated for development at the time of measurement at the construction site. In comparing the predicted and observed values, the simulation models predicted accurately. The predicted value for runoff remained constant, in comparing runoff values for different stages of development, until full development. At the full development stage, runoff increased approximately 237 percent in relation to the development at the time of measurement. The potential error in this test due to the opportunity to calibrate the model at only one level of development should be noted.

Eighty-one percent of the lot owners in the Ponderosa Pines development planned on some form of construction according to a confidential questionnaire. This approaches the full development situation that the modeling effort showed to be hazardous to water quality. Land owners should be more acutely aware of the potential hazards of disturbing water quality as a result of their construction activity. It is believed that good management will diminish the negative effects caused by the increase in construction development.

Several variables proved to be good estimators in predicting second-home development for the Cloudcroft region. These variables included the number of land transactions, the deflated lagged price of crude oil, and the consumer price index for private transportation. These variables were used in several combinations, accounting for 90 percent of the variation of second-home development. The models generated in this study have a very short run nature and may not hold up in the long run. Problems in the long run may result from a break-down in the relationship between crude oil and transportation and development in small forested watersheds.

This study should be expanded to incorporate additional observations to assure accuracy and reliability of results. Increased observations would also increase the confidence when extrapolating research results to other similar watersheds.

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APPENDIX A

KINGEN 75 SIMULATION MODEL

KINGEN 75 SIMULATION MODEL

Program Description

The model consists of the program MAIN and the following 19 subroutines:

1.	READER:	Reads in model parameters, watershed geometry data and rainfall data. Called from MAIN.
2.	INSPEC:	Inspects input data for errors and prints out an error message, if one is detected.
3.	RESET:	Places input data read by sub-routine READER into appropriate arrays. This is done so that no subscripts are necessary on the data cards.
4.	CONVERT:	Converts units of time and length in input data to units used internally and reconverts to desired units in output.
5.	PLANE:	Finite difference solution for overland flow on a plane. A four-point implicit method is used.
6.	CHANNEL:	Implicit finite difference solution for unsteady flow in channels with trapezoidal or circular cross sections.
7.	EPLINF:	Computes infiltration rates. Called only from PLANE.
8.	ADD:	Adds specified discharges (lateral flow and channel junctions): and computes upstream boundary values (depth, area or intersection angle in conduits).
9.	RESLAW:	Calculates the parameters for the hydraulic resistance law selected in the imput.

10.	CHGLAW:	Changes the hydraulic resistance laws at the transition Reynolds number if Laminar-Turbulent option has been selected.
11.	UNIF:	Uses linear interpolation to convert a list of discharge values at irregular time increments into a list with regular time increments.
12.	INTHUB:	Calculates a residual function for an assumed value of the independent variable, 8, in the iterative solution of the upper boundary area of a circular conduit, given an upstream discharge Q from ADD. Called from ADD through ITER.
13.	IMPLCT:	Four-point implicit finite difference scheme. Called from sub-routines PLANE AND CHANNEL.
14.	ITER:	Newton-Raphson iteration scheme to solve general non-linear equations of the form F(x) = 0. Called from sub-routine IMPLCT.
15.	IMPOCH:	Calculates a residual function for an assumed depth h in the iterative solution of depth along a plane. Called from IMPLCT through ITER.
16.	IMPCHA:	Calculates a residual function for an assumed area in theiterative solution for cross-sectional area in a trapezoidal channel. Called from IMPLCT through ITER.
17.	IMPCIR:	Calculates a residual function for an assumed value of the independent variable in the iterative solution for cross-sectional area in a circular channel. Called from IMPLCT through ITER.

18. IMPAUB: Calculates a residual function for an assumed area in the iterative solution for the upper bound area of a trapezoidal channel, given an upstream discharge. Called from ADD through ITER.

19. ERROR: Prints appropriate error messages.

The flow chart for the KINGEN 75 Model is shown in appendix figure 13. The model operates as follows:

A. Identification of cascade of planes and channels. This follows a logical flow sequence of overland flow planes and channels.

B. Input initial conditions and rainfall data.

C. Initialize variables. All variables are initialized to zero.

D. Input geometry. Slope, roughness, and location in the cascade of each element are entered.

E. Surface perviousness. At this point if the plane or channel is pervious the program will require the infiltration parameters, if impervious the computation will go to the next plane or channel.

F. Input infiltration data.

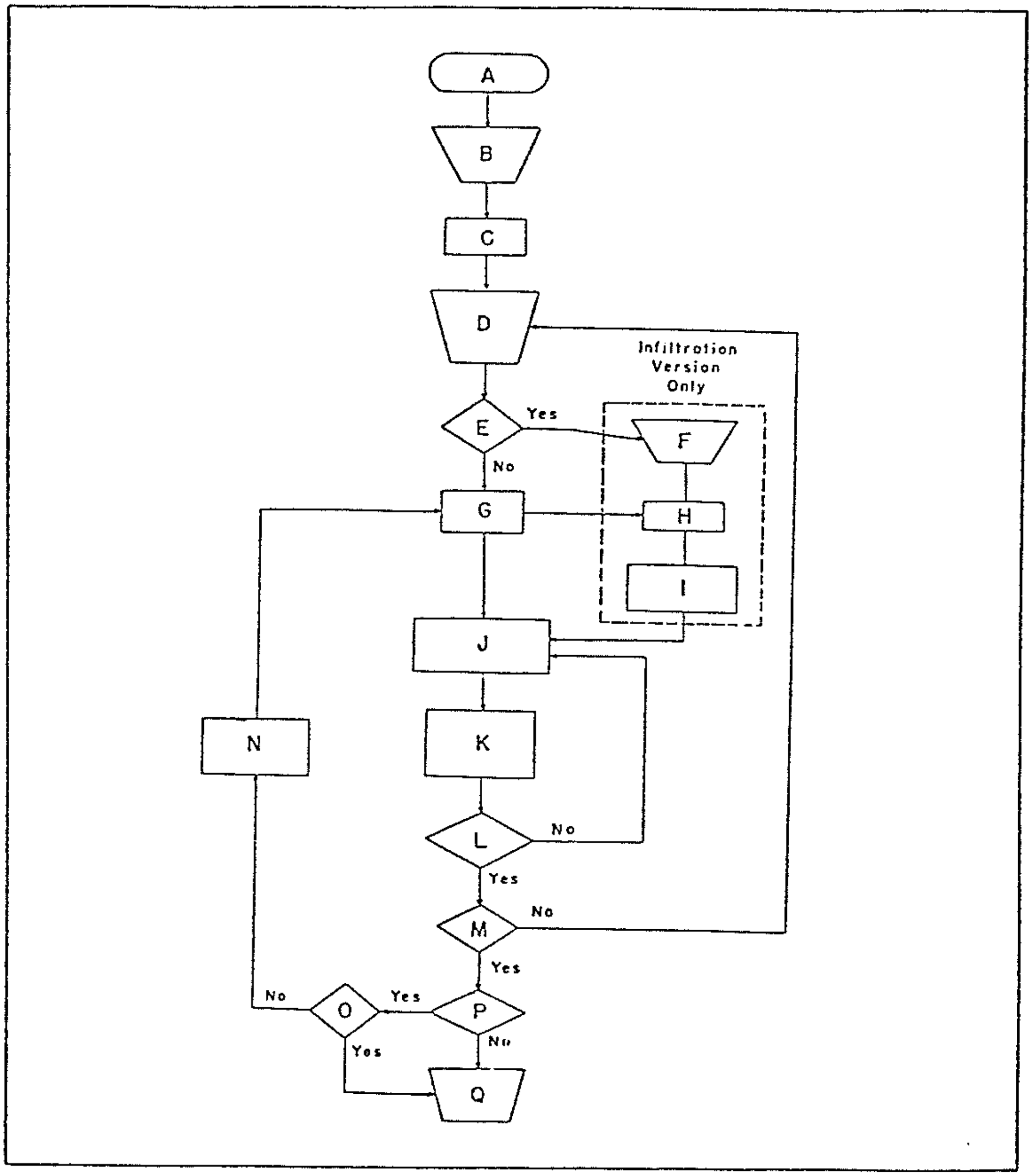
G. Choose laminar or turbulent flow regimes. Compute the roughness coefficients if the element is impervious.

H. Compute runoff. Compute the roughness coefficients for pervious elements.

I. Compute rainfall excess using sub-routine XPLINF. This subroutine computes infiltration rates and returns excess rainfall for a new time increment.

J. Compute downstream boundary depth and the new time increment.

K. Compute depth on surface or area in a channel; D/S discharge.



Appendix Figure 1. Flow chart of program Kingen 75.

L. Has end time been reached? The length of the time increment is compared to the length of the hydrograph to check if the end time has been reached.

M. Last segment? Check to see if it is the last element to be processed.

N. Single variable optimization sub-routine. UNIOP not operative in KINGEN 75.

O. End Criterion? Not operative in KINGEN 75.

P. Optimization: Not operative in KINGEN 75.

Q. Final hydrograph. This gives us the output for the predicted hydrograph.

In a stepwise fashion, the model, using sub-routine 1-4, reads in the basic data and converts it to computer format and proper measurement units. If the surface is pervious, the model computes infiltration rates using sub-routine XPLINF with information taken from PLANE, the sub-routine generating overland flow. Sub-routines 5, 8, 10, 11, 17 and 18 operate to calculate the final output (a hydrograph expected for a given site), assuming a level of precipitation within the simulated watershed.

Basic Input Data Description

NELE: Number of elements in the system. The maximum allowed is 20 elements.

NRES: Resistance law code. It allows to choose the hydraulic resistance to be used.

CLEN: Characteristic length (normally set equal to the sum of the lengths of the longest cascade of planes in the system or the longest single channel, whichever is greatest).

TFIN: Desired maximum duration of the runoff event.

DELT: Desired time increment for computations and for printout of hydrograph.

THETA: Weighting factor in the implicit numerical solution.

NOPT: A code reserved to allow an optimization sub-routine to be added. This option is not operative in Kingen 75.

NTIME: Time units code. It refers to the time units of the input and output data.

KUNIT: Code referring to input units. All internal calculations are done in English units.

NLOG(1): Contains the index number assigned to planes and channels in the order in which computations should proceed.

NU: Number of the plane element contributing to the upstream boundary of element J.

NR: Number of plane contributing lateral inflow to the right side of the channel. It is omitted for a plane element.

NL: Number of plane contributing to the left side of the channel. It is omitted for a plane element.

NC1 and NC2: Number of channels contributing at the upstream boundary of a channel.

NCASE: Code to indicate the type of channel cross section.

NPRINT: Code to obtain or suppress printout of output from any element.

J: The element number.

XL: Length of plane.

W: Width of element. Set equal to zero when the element is a channel.

S: Slope.

ZR: Right-side slope of a channel.

ZL: Left-side slope of a channel.

A: Height of the bottom of the channel.

DIAM: Pipe diameter.

R1: Turbulent law roughness parameter.

R2: Laminar law parameter.

FMIN: Minimum infiltration rate for element.

AL: Exponent parameter for decay curve.

B: Ponding time parameter.

C: Infiltration scaling parameter.

SI: Initial volumetric relative water content.

SMAX: Maximum volumetric water content under inhibition.

ROC: Volumetric relative rock content.

QI(1): Rainfall rate (iph or cm/min). iph units were used.

TI(1): The time at which the corresponding rainfall rate begins.

ND: The number of rainfall data pairs.

TI(ND): Should be greater than TFIN so that the rainfall rate can be defined throughout the event.

Because the optimization option is inoperative in Kingen 75, the card RAIN is the last item of input.

Two listings of the program are presented in Appendix B.

APPENDIX B

COMPUTER DATA

Computer Data for the Stage of Development Road Only

```
εBEGIN NELE=10,NRES=1,CLEN=201.,2,TFIN=146.,DELT=2.,THETA=0.8 εEND
εOPTION NOPT=0,NTIME=2,NUNITS=1 εEND
εORDER NLOG(1)=1,2,3,4,5,6,7,8,9,10 εEND
εFIRST J=1,NU=0,NPRINT=1 εEND
εSECOND J=1,XL=136.,W=168.,S=0.101,R1=0.101,R1=0.325,FMIN=0.1055 εEND
εTHIRD J=1,AL=0.51,B=0.80,C=8417.,SI=0.30,SMAX=0.90,ROC=0,40 εEND
εFIRST J=2,NU=0,NPRINT=1 εEND
εSECOND J=2,XL=95.,W=168.,S=0.0513,R1=0.0513,R1=0.325,FMIN=0.1055 εEND
εTHIRD J=2,AL=0.51,B=0.80,C=8417.,SI=0.30,SMAX=0.90,ROC=0.40 εEND
εFIRST J=3,NU=0,NR=2,NL=1,NC1=0,NC2=0,NCASE=1,NPRINT=1 εEND
εSECOND J=3,XL=168.,W=0.,S=0.119,ZL=0.12,ZR=0.1,A=0.05,R1=0.325,
 FMIN=0.1055 εEND
εTHIRD J=3,AL=0.51,B=0.80,C=8417.,SI=0.30,SMAX=0.90,ROC=0.40 εEND
εFIRST J=4,NU=0,NR=0,NL=0,NC1=3,NC2=0,NCASE=2,NPRINT=1 εEND
εSECOND J=4,XL=55.,W=0.,S=0.0727,DIAM=1.04,R1=0.023,FMIN=0.0 εEND
εFIRST J=5,NU=0,NPRINT=1 εEND
εSECOND J=5,XL=150.5,W=95.,S=0.1138,R1=0.325,FMIN=0.1055 εEND
εTHIRD J=5,AL=0.51,B=0.80,C=8417.,SI=0.30,SMAX=0.90,ROC=0.40 εEND
εFIRST J=6,NU=5,NPRINT=1 εEND
εSECOND J=6,XL=154.,W=95.,S=0.0850,R1=0.021,FMIN=0.00 εEND
εFIRST J=7,NU=6,NPRINT=1 εEND
εSECOND J=7,XL=201.2,W=95.,S=0.1300,R1=0.325,FMIN=0.1055 εEND
εTHIRD J=7,AL=0.51,B=0.80,C=8417.,SI=0.30,SMAX=0.90,ROC=0.40 εEND
εFIRST J=8,NU=0,NPRINT=1 εEND
εSECOND J=8,XL=68.,W=95.,S=0.1030,R1=0.021,FMIN=0.00 εEND
εFIRST J=9,NU=8,NPRINT=1 εEND
εSECOND J=9,XL=61.,W=95.,S=0.0656,R1=0.325,FMIN=0.1055 εEND
εTHIRD J=9,AL=0.51,B=0.80,C=8417.,SI=0.30,SMAX=0.90,ROC=0.40 εEND
εFIRST J=10,NU=0,NR=7,NL=9,NC1=4,NC2=0,NCASE=1,NPRINT=2 εEND
εSECOND J=10,XL=95.,W=0.,S=0.1263,ZL=0.5,ZR=0.33,A=0.3,R1=0.325,
 FMIN=0.1055 εEND
εTHIRD J=10,AL=0.51,B=0.80,C=8417.,SI=0.30,SMAX=0.90,ROC=0.40 εEND
εRAIN QI(1)=0.54,0.00,0.00,TI(1)=0.00,100.,150.,ND=3 εEND
```

Computer Data for the Full Stage of Development

```
εBEGIN NELE=12,NRES=1,CLEN=220.2,TFIN=146.,DELT2.,THETA=0.8 εEND
εOPTION NOPT=0,NTIME=2,NUNITS=1 εEND
εORDER NLOG(1)=1,2,3,4,5,6,7,8,9,10,11,12 εEND
εFIRST J=1,NU=0,NPRINT=1 εEND
εSECOND J=1,XL=136.,W=168.,S=0.1010,R1=0.325,FMIN=0.1055 εEND
εTHIRD J=1,AL=0.51,B=0.80,C=8417.,SI=0.30,SMAX=0.90,ROC=0.40 εEND
εFIRST J=2,NU=0,NPRINT=1 εEND
εSECOND J=2,XL=95.,W=168.,S=0.0513,R1=0.325,FMIN=0.1055 εEND
εTHIRD J=2,AL=0.51,B=0.80,C=8417.,SI=0.30,SMAX=0.90,ROC=0.40 εEND
εFIRST J=3,NU=0,NR=2,NL=1,NC1=0,NC2=0,NCASE=1,NPRINT=1 εEND
εSECOND J=3,XL=168.,W=0.,S=0.119,ZL=0.12,ZR=0.10,A=0.05,R1=0.325,
 FMIN=0.1055 εEND
εTHIRD J=3,AL=0.51,B=0.80,C8417.,SI=0.30,SMAX=0.90,ROC=0.40 εEND
εFIRST J=4,NU=0,NR=0,NL=0,NC1=3,NC2=0,NCASE=2,NPRINT=1 εEND
εSECOND J=4,XL=55.,W=0.,S=0.0727,DIAM=1.04,R1=0.023,FMIN=0.0 εEND
εFIRST J=5,NU=0,NPRINT=1 εEND
εSECOND J=5,XL=15.8,W=95.,S=0.0533,R1=0.012,FMIN=0.00 εEND
εFIRST J=6,NU=5,NPRINT=1 εEND
εSECOND J=6,XL=68.5,W=95.,S=0.1138,R1=0.325,FMIN=0.1055 εEND
εTHIRD J=6,AL=0.51,B=0.80,C=8417.,SI=0.30,SMAX=0.90,ROC=0.40 εEND
εFIRST J=7,NU=6,NPRINT=1 εEND
εSECOND J=7,XL=220.2,W=95.,S=0.0850,R1=0.021,FMIN=0.0 εEND
εFIRST J=8,NU=7,NPRINT=1 εEND
εSECOND J=8,XL=63.2, W=95.,S=0.0767,R1=0.012,FMIN=0.0 εEND
εFIRST J=9,NU=8,NPRINT=1 εEND
εSECOND J=9,XL=138.,W=95.,S=0.1300,R1=0.325,FMIN=0.1055 εEND
εTHIRD J=9,AL=0.51,B=0.80,C=8417.,SI=0.30,SMAX=0.90,ROC=0.40 εEND
εFIRST J=10,Nu=0,NPRINT=1 εEND
εSECOND J=10,XL=68.,W=95.,S=0.1030,R1=0.021,FMIN0.0 εEND
εFIRST J=11, NU=10,NPRINT=1 εEND
εSECOND J=11,XL=61.,W=95.,S=0.0656,R1=0.325,FMIN=0.1055 εEND
εTHIRD J=11,AL=0.51,B=0.80,C=8417.,SI=0.30,SMAX=0.90,ROC=0.40 εEND
εFIRST J=12,NU=0,NR=9,NL=11,NC1=4,NC2=0,NCASE=1,NPRINT=2 εEND
εSECOND J=12,XL=95.,W=0.,S=0.1263,ZL=0.5,ZR=0.33,A=0.3,R1=0.325,
 FMIN=0.1055 εEND
εTHIRD J=12,AL=0.51,B=0.80,C=8417.,SI=0.30,SMAX=0.90,ROC=0.40 εEND
εRAIN QI(1)=0.540,0.00,0.00,TI(1)=0.00,100.,150.,ND=3 εEND
```

APPENDIX C

CONFIDENTIAL QUESTIONNAIRE

NEW MEXICO STATE UNIVERSITY
DEPARTMENTS OF
AGRICULTURAL ENGINEERING
AND
AGRICULTURAL ECONOMICS AND AGRICULTURAL BUSINESS

Confidential Questionnaire
Small Watersheds Project

1979-1980

The information requested on this form will remain confidential. It is to be used in a computer model to simulate the possible impacts, on water quality, of alternative mountain home design, location, and landscaping. Thank you for your assistance.

I. Construction and Type:

1. Will this lot be developed? (check one)

	Lot & Blk.	Yes	No	If yes, give type of dev.
1.		81%	19%	

2. Is the intended use of the property primarily for (check one)
23.8% Permanent Home   28.5% Vacation Home
19.04% Investment only   28.6% Vacation & Investment

3. Describe your mountain home (existing or planned) in terms of the following (check appropriate blank or, if some combination applies, indicate percentage of each)

Type of construction: Log 11.7% Wood Frame 76.4%
Brick Venneer 5.8% Slump Block 5.8%

Major heating source: Electricity 23.5% Propane 5.8%
Electricity & Wood 23.5% Electricity & Butane 11.7%
Woodstove and/or Fireplace 23.5%

Insulation: Storm doors 52.9% Storm windows 70.5% Insulation in ceiling 94.1% Insulation in walls 88.2%

4. Will your planned home (excluding the basement) be:
single story 58.8% multi-story 29.4% A-frame 5.9%
split level 5.9%

5. Do you expect to build any other structures (such as storage sheds, stables, etc.) on your property? Yes 5.9% No 94.1%

6. Will your planned home have a basement? Yes 35.3% No 64.7%
If yes, what type? (check one) Partial 83.3% Full 16.7%

7. When do you expect to start building? When do you expect to complete construction? (month, year)
Already completed 17.6% 1979 17.6% 1980 23.5% 1986 5.9%
Unknown 35.3%

9. Do you have access to a developed water system or will it be necessary to drill a well? (check one)
Developed water system 94.1%
Necessary to drill, depth (feet) 5.9%

10. What type of sewage system do you expect to use?
Septic 100%

11. Why did you choose this location for building your home?
Asthetic beauty of area 58.5% Investment 23.5% Mixed 18%

12. Will you have an automatic washing machine in your home?
Yes 52.9% No 47.1% Dishwasher? Yes 35.3% No 64.7%

13. During the construction phase, where will you purchase most of the construction materials?
Lumber Las Cruces--23.5%, Alamo 11.8%, Weed--5.9%, Locally--17.6%, Unknown--58.8%
Concrete Las Cruces--11.8%, Cloudcroft--17.6%, Alamo--17.6%, Locally--17.6%, Unknown--35.3%
Hardware Las Cruces--29.4%, Alamo--17.6%, Locally--11.8%, Unknown--58.8%

II. Landscape:

1. Will it be necessary to construct an access road or driveway from outside roads to your planned home? Yes 47.0% No 53%. If yes, indicate type of road planned (for example, dirt, gravel, or paved).
Gravel 100% Length 550 ft.--50.0%, 750 ft.--37.5% Unknown--12.5%

2. How do you plan to landscape the property? Natural (no change) 88.2% Natural & Grass 5.9% Unknown 5.9%

3. Relative to homes already constructed in the development, how much site preparation will be necessary?
Very Little 52.9% Modest Amount 35.2% Unknown 11.76%

III. Socio-Economic:

1. Do you currently own or expect to own off-road recreational vehicles for use in the vicinity of your property? Yes 23.5% No 76.5% If yes, specify the type Bronco--50%, Chevy--25%, Jeep--25%

2. Do you plan to board horses on your property? Yes 0 No 100%

3. What type of recreational activity do you expect to participate in while residing at your planned home?

Hiking 70.5% Boating 5.9% Tennis 58.8% Golf 64.7%
Other (specify) Ski 11.8% Run 11.8% Fish 11.8% Hunt 5.9%

4. What is the number and ages of people that will be living in your planned home?

Number

1 = 11.7
2 = 41.1
3 = 11.7
4 = 23.5
5 = 0
6 = 5.9
No Answer = 5.9

Ages (% of household share ages in home)

0-10 = 23.5
11-15 = 23.5
16-20 = 5.9
21-25 = 11.7
26-30 = 41.1
31-35 = 58.8
36-40 = 11.7
41-45 = 5.9
46-50 = 29.4
51-55 = 11.7
46-60 = 11.7
More than 60 = 11.7

Average age of 2 main employed = 38.6 years