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A STUDY OF

# GROUNDWATER MOVEMENT IN LANDSLIDES

IDH-RP 02

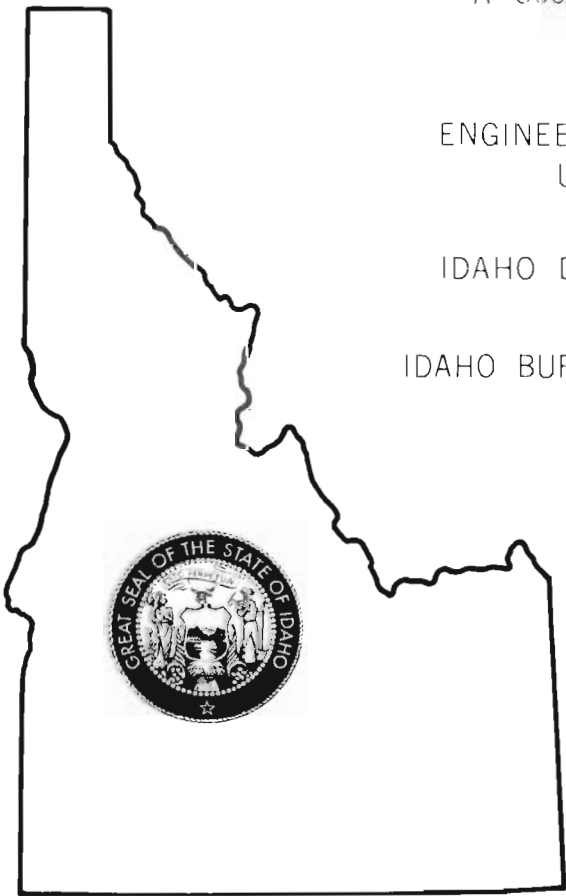
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## CHAPTER I

### INTRODUCTION

Landslides have been recognized as an increasingly important item to be considered in the design of soil-related structures. Economic and legal aspects are now carefully weighed before decisions are made concerning proposed projects in areas susceptible to landslides.

Demands for better highways have resulted in longer and deeper cuts and higher fills. Urban expansion has caused areas to be developed that are less desirable than many earlier developments from the standpoint of potential landslide damage. A new outlook on legal responsibility with relation to landslides has developed. It is now realized that landslides are not necessarily "acts of God" as was the early-day explanation (21). McNeal (21) states that:

"The engineer is faced not only with the increased possibility of landslides, but also with greater economic losses and greater chances for injuries and deaths when landslides occur."

With these thoughts in mind the natural question should be, "since this and future generations are faced with the necessity of creating conditions conducive to landslides, what would be the best approach, in most cases, to attack the problem of landslides?" The most obvious answer is not necessarily to curtail all expansion or development that contributes to landslides, but to study, understand, and cope with the basic mechanics of soil mass movement.

The most important factor causing soil mass movement is the reduction in available soil shearing strength to the point that instability exists or failure occurs. That water is the principal agent in reducing the shear strength has long been recognized. Methods of reducing the effects of groundwater have been devised and have proven very successful in many cases; however, since the groundwater cannot be visually observed in its natural state, control measures have not always been successful.

Methods are needed to determine the source and the flow characteristics of groundwater in potential or active landslide areas. This would allow a more efficient and practical engineering approach to the control of water that contributes to landslides.

#### I. PURPOSE

The Idaho Department of Highways annually spends many thousands of dollars on landslides. These expenses can be separated into: (1) costs of initial planning aimed at selection of routes and the purchase of

right-of-way that will minimize the occurrence of landslides, (2) costs of exploration and design directed toward preventing landslides, or at least of making allowances for them, (3) increases in construction costs due to landslide conditions, and (4) costs arising after construction, such as payment for additional right-of-way and increased maintenance costs, which can continue for many years.

Since groundwater is responsible for the majority of landslides in Idaho, the purpose of this research project was to explore methods of delineating groundwater movement in potential or active landslide areas. These methods should necessarily be of such a nature that they can be readily incorporated into the Department of Highways' exploration and construction program. The value of the methods will be measured not by their complexity, but by their reliability, adaptability, and usefulness.

## II. OBJECTIVE

The object of this investigation was to determine if there are any methods of delineating groundwater movement in potential landslide areas, and if there are, to show how these methods can be used by the Department of Highways.

Special emphasis was placed on the use of tracers composed of either chemical dyes or radioactive tritium. Studies of field hydraulic conductivity tests were performed and were incorporated into the overall objective.

It was of primary concern to present to the highway department a simple, yet effective, procedure for delineating groundwater movement in the various, highly different, soil masses within which landslides occur.

## III. LITERATURE SEARCH

The literature search was directed at gaining information on using tracers and on determining hydraulic conductivity. This information was important for designing subsequent laboratory and field experiments.

### Tracers

The use of tracers as a method to follow groundwater movement in potential landslide areas or within and adjacent to existing landslides was not known to have been previously investigated. Numerous attempts have been made to apply tracers to a study of groundwater movement not associated with landslides and many of these have been reported in the literature. Only a few of the more pertinent investigations were selected for incorporation in this paper.

One of the most famous early investigations was conducted by A. Trillat (29) in 1899. Certain dyes, as flow indicators, and the effects of the dyes on the soil passages were studied. The fluoroscope, used to detect minute concentrations of fluorescein dyes, was invented by Trillat.



Winter (26) ran several laboratory and field experiments using salt as a tracer. He concluded that salt when mixed with water formed an electrolyte which allowed the time of first arrival to be determined electrically. He also studied the inflection point of the curve showing the concentration of salt as it varied with time. One obstacle to using salt as a tracer is the creation of density problems and ion exchange phenomena that can affect the results.

Dole (6) reported on the French experiments in which fluorescein was used to study groundwater movement. Fluorescein proved to be effective in tracing the movement of water through sandy and clayey materials, but was ineffective when used in highly organic materials because the fluorescein was adsorbed on the soil particles. The fluorescent qualities of fluorescein were affected by addition of certain acids; a fact that Dole applied to the investigation.

The New York State Health Department (2) has published instructions on the use of fluorescein for tracing water pollution, including field methods of detecting minute concentrations of fluorescein in solution. The fluorescent qualities of fluorescein have been reported to be destroyed by acids.

Kaufman and Orlob, in experiments with both radioactive and chemical tracers (13) (14) reported that chloride, dextrose, fluorescein and iodine 131 were used as tracers. Solutions containing these tracers were passed through California farm soils, and it was shown that the order of best performance was respectively, chloride, dextrose, fluorescein and iodine 131. In further studies fluorescein was the most satisfactory of the chemical dyes, and tritium performed better than any other radioactive isotope. Soils with large amounts of organic matter reacted with the fluorescein and sometimes yielded unreliable results. Chloride showed a tendency to disperse the soil colloids, thus changing the permeability.

Schoeller (24) did an extensive literature survey on groundwater tracers and listed the results of many tracer applications. Tests have been performed in many parts of the world and by people associated with many different disciplines, such as hydrology, hydrogeology, petro-geology and sanitation.

The value of radioactive materials as a tracer led Kaufman (12) to investigate and report on the potential hazard to the public of tracing potable water supplies with radioactive tritium. He concluded that tritium, in the low concentrations necessary for tracing water, would be relatively harmless to people utilizing the "tagged" water. Tritium was stated to be the most ideal of all tracers.

Freely and others (9) outlined and discussed the history of radioactive isotopes in tracing groundwater. They concluded that tritium appeared to be the most dependable groundwater tracer. The importance of using chelates with anions was recognized and seemed to offer the greatest hope for successful tracing. A very complete bibliography was presented.

Laboratory experiments performed by Heemstra and others (11) on nine radioactive water tracers substantiated the superiority of tritium for the conditions of the selected tests. The test results showed little preferential adsorption of tritiated water. The investigators concluded that anions and anion complexes are subject to less loss through a soil column than the cations.

An elaborate tracing program conducted in the field at the Chalk River Site, Atomic Energy Commission of Canada, showed the value of using several tracers in solving a complex problem. Parsons (23) reported that tritium, sulfur 35, and fluorescein were all mixed in the same solution and injected into the groundwater system. Subsequent sampling and analyses showed that tritium moved the fastest, then sulfur 35, and fluorescein only about 75 per cent as fast as tritium.

Fluorescent tracers, fluorescein, pontacyl brilliant pink, and rhodamine b, were investigated in the laboratory by Feuerstein and Selleck (8). They found that rhodamine was most highly adsorbed, that fluorescein was present in almost any water and was subject to a high photochemical decay rate, and that pontacyl was superior to the others in marking surface water.

#### Hydraulic Conductivity Tests

Several methods of determining hydraulic conductivity have been devised for both laboratory and field testing. Because of the difficulty of reproducing field conditions in the laboratory, it is the opinion of most investigators that the field methods are far superior and will yield much more valuable information than will the laboratory tests.

Wenzel (32) outlined the direct and indirect laboratory methods, and the groundwater velocity and discharging-well methods as a field approach to determine hydraulic conductivity.

Kirkham (17) proposed a method for field measurement of hydraulic conductivity below the water table. Frevert and Kirkham (10) later modified the Kirkham test method.

Von Bavel and Kirkham (31) proposed the use of a single auger hole for determining hydraulic conductivity. This method alleviates the problem of determining the flow pattern function, the "A" function, that must be considered when using metal tubes or piezometers. The auger-hole method has many advantages over cased-hole or piezometer methods, but it also has a disadvantage because the hole will not remain open in some soils.

The theory of seepage into an auger hole was developed by Kirkham (18) assuming the hole is above an impermeable layer. This was an advancement over the old theory that was based on the case where the auger hole extended to an impermeable layer.

Luthin (19) edited many articles concerned with the drainage of agricultural lands, and included articles that discussed methods of determining the hydraulic conductivity.

Transmissibility coefficients, which when divided by the aquifer thickness yield hydraulic conductivity, were determined by Skibitzke (25) in his bailed-well tests. Ferris and Knowles (7) showed that the theory proposed by Skibitzke also applied to slug-injection tests if the residual head was small when compared to the depth of water in the well.

Winger (33) proposed four useful methods of determining in-place hydraulic conductivity. These were: (1) the auger-hole method, (2) the piezometer method, (3) the shallow well pump-in method, and (4) the permeameter method. He stated that a combination of these methods may be useful in solving certain problems.

## CHAPTER II

### FUNDAMENTAL CONCEPTS

#### LANDSLIDES

The term landslide, as used herein, means the slow or rapid movement of a large soil mass with gravity furnishing the driving force. The soil mass moves downward, and possibly outward, because the shear strength is insufficient as a stabilizing force. Of special interest in this study is the mass movement of soil that occurs because the presence of groundwater causes a lowering of shear strength.

#### Problems Created by Landslides

Active or potential landslides often create many problems. Some of the main factors which must be considered in relation to landslides are:

1. The possibility of endangering human life if sliding occurs.
2. The most economical design to prevent landslides.
3. The costs associated with preventive design and construction, or the repair of the area after sliding has occurred.
4. Resolving the liability of damages.
5. Indirect costs, such as, traffic delay, interruption of utility and other services, and possibly other items.

Landslides have at one time or another, either directly or indirectly, affected many types of business in the United States. Presently, highways, railroads, canals, reservoirs, and urban development projects are being greatly affected by landslides.

#### Causes of Landslides

All landslides are the result of an unstable condition and there are several ways for the stability balance to be upset. Some of these are: cutting off the toe of a stable slope; loading a slope; seismic, vibratory, and other dynamic effects; progressive structural weakening of the involved material; and changes of the groundwater regime.

Terzaghi (28) states that the causes of landslides can be divided into external and internal causes. External causes result from increasing the driving force without changing the resisting force. Internal causes are those in which failure occurs without any preceding change in surface features or without vibratory or earthquake shocks.

In the case of landslides of interest to the Department of Highways, both external and internal causes contribute to the instability. Steepening of slopes by excavation increases the external force. Similarly loading

of a fill slope is shown in Figure 1 (a). The principle internal causes are the increase in pore water pressure and a loss of cohesion within the material.

With the ever increasing demand for more and better highways, with fewer curves and flatter grades, modern designs provide more opportunities for the external causes to become increasingly greater. Therefore, an attempt must be made to eliminate or at least reduce the principle internal causes, which are a direct result of groundwater, if an advance is to be made in stabilizing potential landslides.

"Lubricating" effect of groundwater. A loss of shearing strength occurs in a soil mass when groundwater enters the soil mass. In the past (and even now by some people) it was commonly thought that this loss of strength was due to the water lubricating soil grains so that they more easily slide over and past one another. However, it has been pointed out by Terzaghi (28) and Taylor (27), and many others that the lubricating effect is negligible in most soils. Lubrication may play a minor role in reducing the shear strength when the soil particles are held together by a soluble binder, but is usually of minor importance when compared with the other effects of water.

Seepage force approach. An isolated volume element of a soil mass is shown in Figure 1. Both static water conditions and seepage conditions are illustrated. The head loss  $\Delta h$ , that occurs as the water moves from line MN to line OP, represents the energy used in forcing water through the small passages of the soil skeleton. Viscous friction, between the moving water and the water tightly bound in thin films to the soil particles, transmits a drag force from the moving water to the stationary soil particles equal to the head loss,  $\Delta h$ .

This drag force acts in the direction of the flow lines in an isotropic soil only, but it always acts normal to the equipotential lines. This force is known as the seepage force. By taking the isolated soil mass in Figure 1 as a free body and analyzing the forces acting on it for the seepage case, a better understanding of the seepage forces can be realized. The material within the element may be considered as a two-phase mass of soil and water. The forces acting are: (1) the total weight of the soil and water, (2) the resultant of all the intergranular forces acting across the boundaries, and (3) the resultant of all the water pressure forces. The force that maintains equilibrium is the boundary intergranular force sometimes called the restraining force and it must be equal to and opposite in direction to the resultant of the other two forces.

To resolve the weight force and the water pressure force into a combined force the following approach is used: (1) Vector AB, Figure 1 (b), represents the total weight of soil plus water, (2) the resultant water pressure forces are shown as vectors BF and FE and when resolved can be represented by BE. These are not obvious from the combined diagram of the static plus seepage case, but in Figure 1 (c), the forces representing the difference in pressure heads on opposite faces are shown to aid in the understanding. The pressure head on side NO is equal for the static or seepage case, but the pressure head on side OP is different due to the head lost to viscous friction.

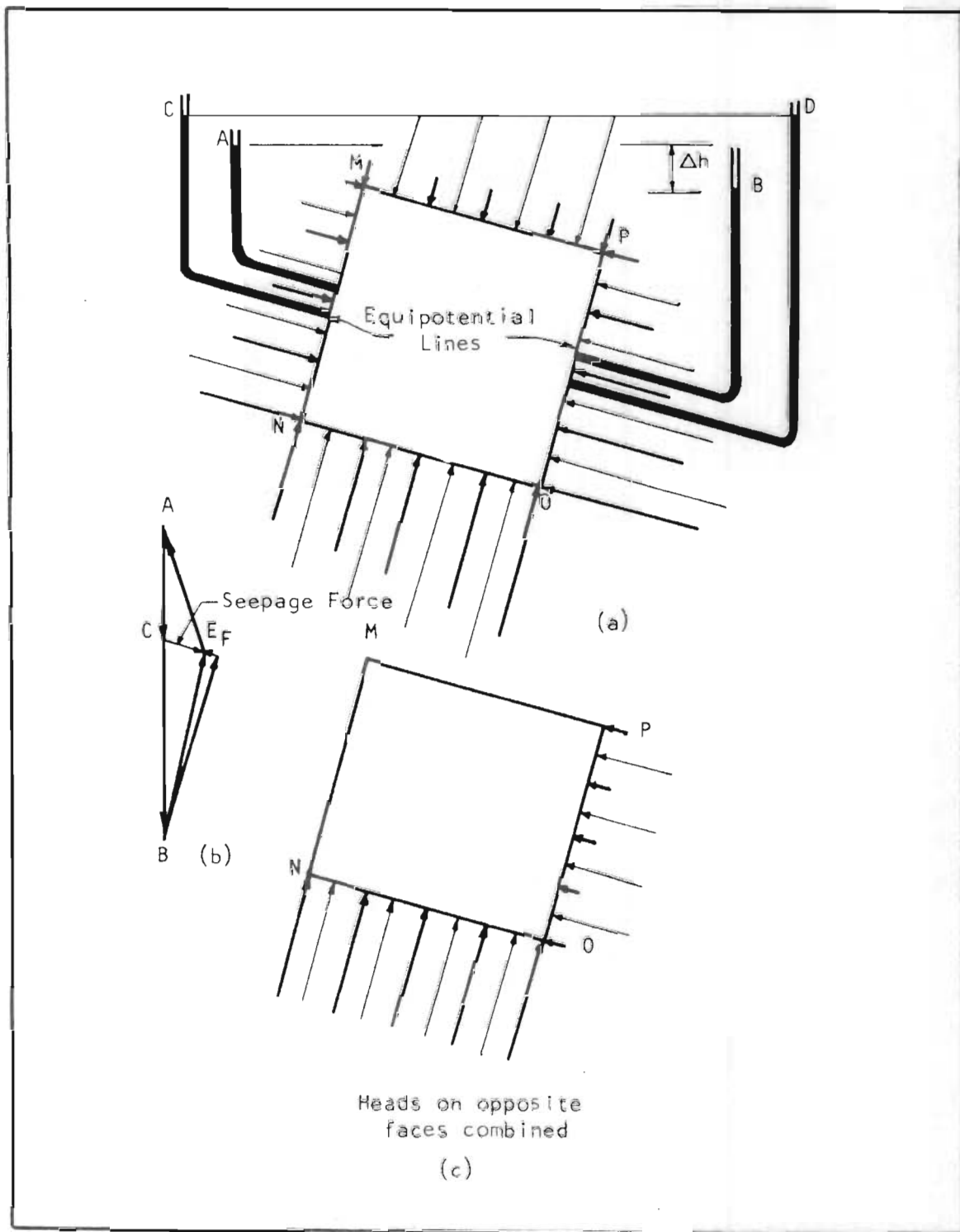


Figure 1. Diagrams of boundary pressures and a force polygon to illustrate seepage forces (After Taylor).

The weight of soil plus water represented by AB, and the resultant of the water pressures represented by BE added vectorially, give the resultant body force AE. Therefore EA must represent all the intergranular forces acting across the boundary. Since AC represents the submerged weight, it is evident that the force CE is a force created by the seepage, and these two added vectorially are equal to the total body force AE.

Extending the considerations from a small element to a large mass, it is easy to see how tremendous forces due to seepage can be developed. These seepage forces act as an actuating force, and they must be counteracted by resisting forces, or else failure occurs.

Pore water pressure approach. The pore water pressure approach yields the same results as the seepage approach with the advantage of being an easier analysis. This analysis is, basically, a determination of the decrease in effective stress at the potential failure surface due to some of the overburden load being carried by pore water pressure. Figure 2 shows how this load is carried. A reduction occurs in the shearing strength as can be seen from Coulomb's Empirical Law

$$\begin{aligned} S &= C_e + N_e \tan \phi_e \\ \text{or} \quad S &= C_e + (N_t - \mu) \tan \phi_e \\ \text{or} \quad S &= C_e + (N_t - \gamma h) \tan \phi_e \end{aligned}$$

where

$S$  = shear resistance

$C_e$  = effective cohesion

$N_e$  = effective stress, intergranular stress

$\phi_e$  = effective friction angle

$N_t$  = normal pressure

$\mu$  = pore water pressure

$\gamma$  = unit weight of water

$h$  = height of piezometer surface above point

Notice that the weight is made up of the soil plus water, so the addition of the water is considered as an addition to the driving force. The additional weight due to the water is not considered to be a very important factor in affecting the stability. However, the normal stress was entirely effective before the water entered into the slope, but after the water entered, the normal stress was made up of pore water pressure plus effective stress. Only the effective stress can be counted on as a stabilizing force. When the stabilizing force is reduced, and possibly cohesion as well, and when driving forces due to tangential components



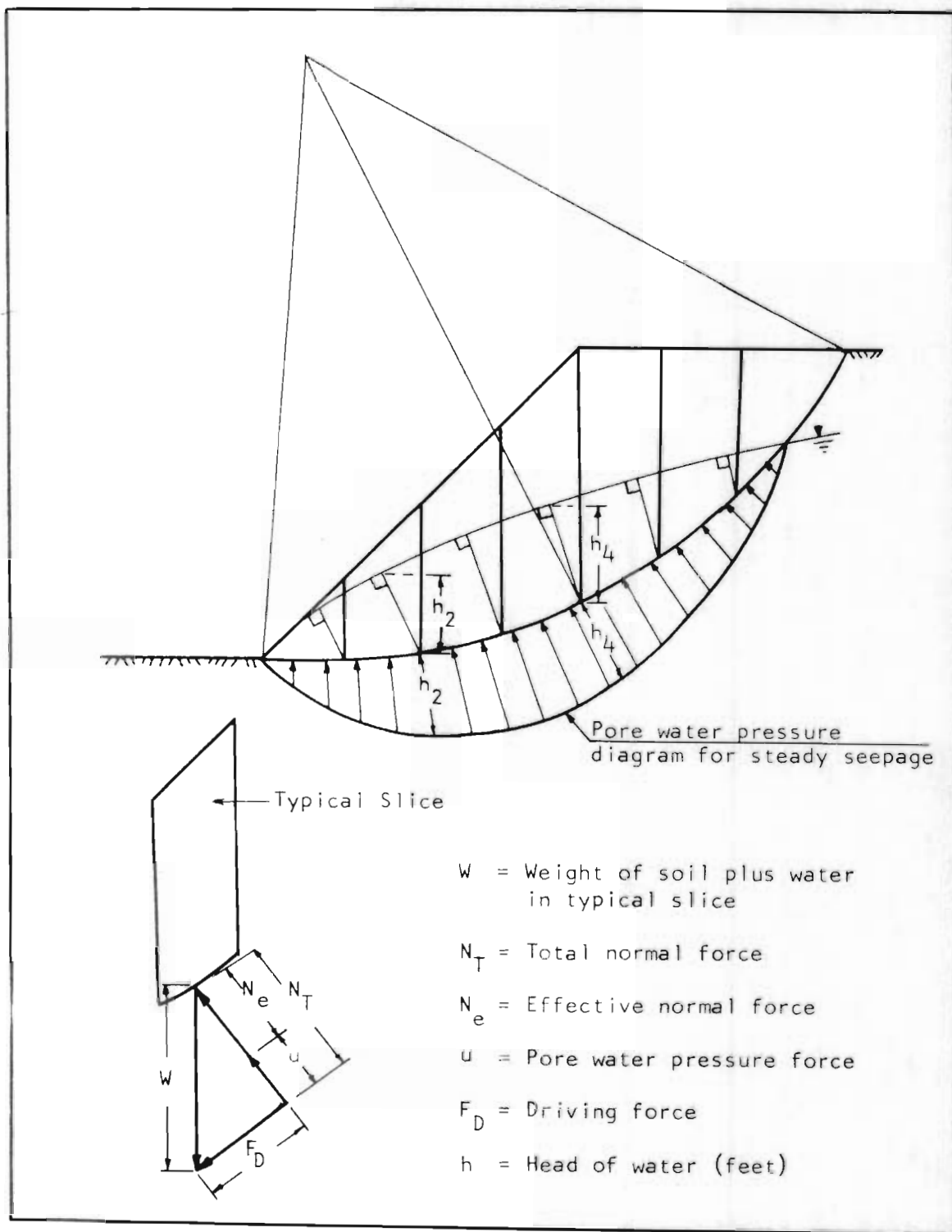


Figure 2. Reduction of slope stability as caused by pore water pressure.



of weight are increased by saturation of the soil mass, the factor of safety against sliding, which is the ratio of the resisting force to the driving force, will be substantially reduced and sometimes failures occur.

## II. WATER MOVEMENT IN LANDSLIDES

### Basic Theory

In soil masses, water can move as either saturated or unsaturated flow. The conditions associated with unsaturated flow are such that this type of flow generally serves as a stabilizing agent when considering stability analyses. The surface tension in the capillary water creates a larger effective force between the soil particles and thus the shear strength is increased.

Saturated flow occurs below the water table. All flow that occurs with water at atmospheric pressure or greater is considered as saturated flow. A thin layer of saturated soil may occur at less than atmospheric pressure just above the water table, but the flow occurring through this layer is considered to be negligible in most analyses.

The basic law for saturated flow through soils was named after its discoverer, Henry Darcy, and it states that the rate of flow is proportional to the gradient of the water table. Darcy's Law is expressed by the equation:

$$\frac{Q}{A} = V = Ki$$

where

Q = quantity of flow

A = cross sectional area of soil mass  
through which the flow occurs

V = velocity

K = hydraulic conductivity

i = the slope or gradient of the water  
table

It should be noted that the velocity,  $V$ , as determined by Darcy's Law is superficial velocity because the quantity of flow,  $Q$ , is divided by the entire cross section including pore spaces plus soil particles. The actual velocity of the water is a seepage velocity which is equal to the quantity,  $Q$ , divided by the area available for flow,  $NA$ , where  $N$  is the effective porosity. Therefore, the relationship between the seepage velocity,  $V_s$ , and the superficial velocity,  $V$ , is  $V_s = V \div N$ . This relationship must be kept in mind as it has a definite bearing on this study.

The hydraulic conductivity,  $K$ , in the Darcy equation is a measure of the ease with which water will pass through a porous material, and is dependent on the characteristics of the porous medium and of the flowing liquid. For some experiments it may be necessary to isolate the properties of the porous medium from those of the flowing liquid, but for the present approach Darcy's Law as presented will suffice.

#### Methods of Measurement

Hydraulic conductivity and groundwater slope. Darcy's Law provides a method of determining not only the quantity or velocity of flow, but also the direction of flow. It is general knowledge that groundwater moves in a direction normal to the equipotential lines or parallel to the maximum water-table gradient. This fact has often been neglected in groundwater studies connected with landslides.

To determine the direction of maximum gradient, a few holes are drilled to a depth below water level in an area and the equilibrium water-level elevations are recorded. Groundwater contour maps are constructed from the readings, and flow lines, normal to the equipotential lines, are drawn. These flow lines are, ideally, the paths of the seepage water movement.

If the area of investigation is small, three holes are drilled in a triangular pattern to a depth below the water table and the water-level elevations are recorded. A triangular plane of the groundwater table is drawn and the direction of water movement is determined by finding the direction of the maximum gradient.

Thus far, only the direction of movement and the maximum gradient have been discussed, but information concerning the velocity is often important to the investigation. This is available by this method only if the hydraulic conductivity can be determined.

Many different field methods have been proposed for determining the hydraulic conductivity of soils in situ. The two most adaptable and effective in most situations are the piezometer and the auger-hole methods. Of these two, the auger-hole method is favored for determining the hydraulic conductivity in active or potential landslide areas. However, the other methods referred to in Chapter 1 should not be entirely discounted as they may be superior in certain cases.

Luthin (19) outlines the development of the auger-hole methods and gives the assumptions and theory from which hydraulic conductivity is calculated. Several approaches to substantiate the theory are also presented. A method of determining hydraulic conductivity, credited to Hooghoudt, is discussed in detail.

Winger (33) does not present the theory, but does present the actual procedure for performing the auger-hole test. He has incorporated charts prepared by Maasland and Haskew in presenting his method of solution.

By taking the average height available to flow for the period under consideration, this procedure recognizes that the water is not flowing through the sides of the auger hole for the entire original water depth in the hole.

The general consensus is that the auger-hole method of determining hydraulic conductivity in the field yields reliable results. The hydraulic conductivity determined by this method is an average value for the soil that the hole penetrated below the groundwater level. Therefore, the velocity calculated by this method is the average, superficial velocity.

Tracers. Many attempts have been made to accurately delineate the basic parameters necessary for determining the flow path of water particles through a soil mass. The methods of determining the movement of water particles are theoretical, analytical, or physical. Because the theoretical and analytical approaches require many assumptions that are usually not entirely met, their reliability is limited. The physical approach therefore has become an accepted tool in determining groundwater movement.

The physical approach, which is tracing, is performed by attaching a traceable material to a water molecule and allowing this "marked" molecule to follow the normal flow path of the groundwater. The actual flow path can be determined by taking samples, fanned out along the preconceived direction of flow, and testing for the presence of the "marked" molecules. Either previously presumed flow paths can be substantiated, or the correct unimagined, flow paths can be constructed. Note that this holds true macroscopically but not microscopically.

Tracer materials are of many kinds and compositions. Some classes of materials that have been used under different conditions and with large variations in effectiveness are:

1. Dyes
2. Chemicals
3. Suspended particles
4. Dissolved gases
5. Bacteria
6. Radioactive isotopes

Not any one tracer is the best for all conditions, but there is a specific tracer that is best for any given condition.

Through the intelligent application of tracers, a more concise description of the physical movement of water through a soil mass is available. Thus the answers to many bewildering questions of groundwater movement are being obtained. The full value of the tracer approach to groundwater problems in landslides, as well as in the many other environments, will probably not be realized until the demands warrant more exact descriptions of groundwater movement.

Problems and limitations. In-situ hydraulic conductivity determinations often have definite problems and limitations connected with

them. There are areas in which neither the piezometer nor the auger-hole method will be satisfactory. In some soil masses, rock will prevent driving a piezometer, and a constant diameter auger hole will be impossible to construct and maintain.

Non-homogeneity of the soil creates problems in making the auger-hole test and in interpreting the resulting data. This test is limited to fairly homogeneous soil masses having medium hydraulic conductivity rates; twenty feet per day would be considered a high rate, and low rates are of such an order that procedural errors may cause significant differences in the results.

The auger-hole method will not work if the soil to be tested is under artesian conditions. If special zones are to be tested separately, the piezometer method probably should be used, but if the interest is in average hydraulic conductivity, the auger-hole method should be used if possible.

In the present study the only reason for performing hydraulic conductivity tests was to allow the velocity of the groundwater to be calculated. This calculated velocity then is used as a criterion upon which the feasibility of performing a tracer test is evaluated. Groundwater tracer tests are of no value unless the information obtained is available within a reasonable length of time.

Any tracer material must be economical in first cost as well as in its utilization and activity monitoring so that the costs will not restrict its use. An ideal tracer should be economical, safe, not present in the original water, capable of following the water movement without altering it, non-adsorbent or nearly so, capable of being detected in low concentrations, and non-reactive with the porous medium.

Limitations for the use of tracers have not been established as a general rule, but four of the most important factors that restrict the use of an otherwise suitable tracer are adsorption, dispersion, filtration, and public acceptance. Adsorption is the adhesion, in very thin layers, of the tracer to the surface of the soil particles, while filtration is the screening or sieving of the suspended tracer material out of solution. Dispersion is the separation or scattering of the tracer material.

## CHAPTER III

### METHOD OF INVESTIGATION

After the problem was defined, a literature review was made in hopes of finding a previous study which could be used as a "take-off" point. Studies pertaining to groundwater movement in potential or active landslides were not reported, or at least were not found, in which the tracer approach was used.

Until recently, little work of any consequence has been done in tracing groundwater. Several isolated and limited applications of tracers have been made, but few comprehensive experiments involving comparisons of several tracers were reported. For this reason a laboratory program was set up to precede and to be run in conjunction with a field program.

#### I. LABORATORY EXPERIMENTS

The object of the laboratory tests was to analyze the behavioral characteristics of several dyes when they were being used as a tracer material to trace water through soil. Primary consideration was to determine: (1) which of the several manufactured dyes would perform best as a tracer material, (2) in what types of soil it would be most effective, and (3) theoretically, how successfully the dyes might be applied to tracing groundwater movement in field conditions. The eight different dyes used as tracers were FD&C Violet #1, FD&C Red #2, gentian violet, poirriers blue, methyl blue, fluorescein, rhodamine, and pontacyl. Preliminary tests showed that only FD&C Red #2, fluorescein, rhodamine, and pontacyl warranted further laboratory testing. The other four dyes were adsorbed or filtered out of solution by the soil particles in very short distances. The apparatus for the laboratory tests are shown in Figure 3. The procedure for the laboratory analyses of water samples is presented in Appendix B.

#### Preparation of Samples

Soil samples were taken from several field test sites and were of five types, including a well-graded coarse sand, a fine sand, silt, a well-graded decomposed granite, and a Palouse loess. A portion of each sample was used in laboratory analyses for gradation, sand equivalent, and Atterberg limits when applicable, while the bulk of the sample was used to make up soil columns. Ottawa sand was also used in some tests. Each soil column was prepared by placing soil in a glass cylinder, the inside of which had been previously coated with petroleum jelly. A certain number of layers of soil with a certain compactive effort on each layer was used to create the desired column. During the experiments, several groups of soil columns were prepared at different compactive efforts and of different lengths.

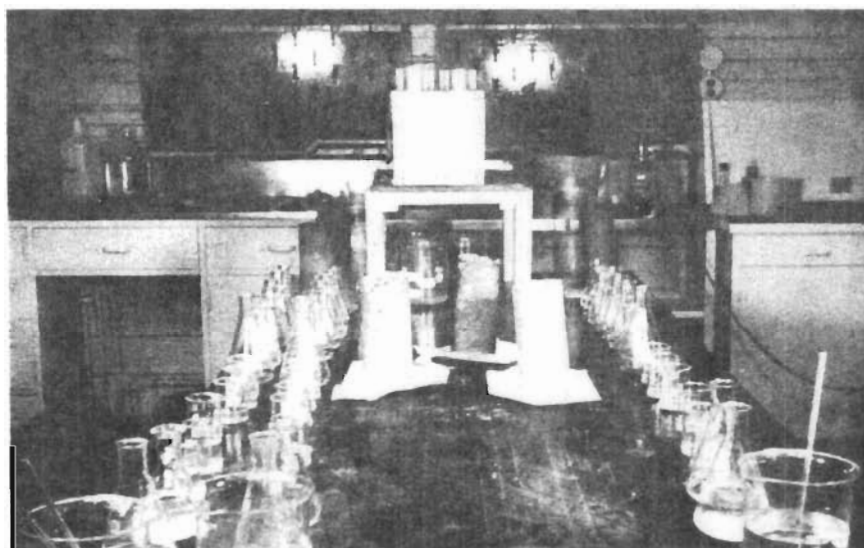


Figure 3. Laboratory experimental apparatus.

Each group of identically prepared soil columns was used in the comparison of the various dyes. Solutions of distilled water and dye were allowed to percolate down through the soil columns in unsaturated flow with a predetermined depth of solution above the soil surface being maintained until the entire solution had been used up. A visual color comparison of samples collected at the bottom of the soil column was made with some prepared knowns. After the dye solution had free-drained from the soil column, distilled water was allowed to percolate through the soil and again solution samples were collected for visual color observations. After the soil column had again been allowed to drain, it was extruded from the glass cylinder and was sliced vertically so further visual examination could be made. By inspecting the vertical cross section of the soil column in conjunction with the visual comparison between the unknown collected solution samples and the prepared known samples, a determination of filtration characteristics and of the adsorption of the dye to the soil particles was made.

After initial laboratory tests were performed as previously outlined, the need for exact measurements of dye concentrations was evident. A Model 110 Turner Fluorometer was available in August, 1964, and it was utilized in subsequent experiments involving fluorescent dyes. For the non-fluorescent dyes, a Model AC Fisher Electrophotometer was used to determine the concentrations of dye in the unknown samples (Figure 4 and 5).

Since the means were available to measure dye concentrations, more detailed laboratory tests were run. Soil columns were prepared and solutions of fluorescein, pontacyl, rhodamine, and FD&C Red #2 were passed through the soil columns. A constant water depth of 2 inches was maintained above the soil surface by adding distilled water as necessary. All of the solution was collected after it had percolated through the soil column by using collection containers. The samples in these containers were then analyzed by either fluorometric or electrophotometric methods and the concentrations of dye were determined. By determining the concentration of the dye in each sample, a relationship between the concentration of dye in the sample and the concentration of the dye in the original solution could be made. Also, the quantity of each sample was measured so that the total dye passing through the soil column could be calculated. The per cents of the different dyes passing through the soil columns were calculated and compared to determine filtration and adsorption characteristics of different dyes in different soils.

#### Chelating Agents

In conjunction with the tests to determine the adsorption of different dyes to soil particles another set of tests was run to determine the effectiveness of chelating agents. Two chelating agents, "blue cheer" and "tetrasodiumpyrophosphate", were separately tested by putting different concentrations into the dye solutions. The concentration of the chelating agent was varied from 0-3200 ppm and its ability to prevent adsorption was studied.



Figure 4. Fluorometer for monitoring dye samples.

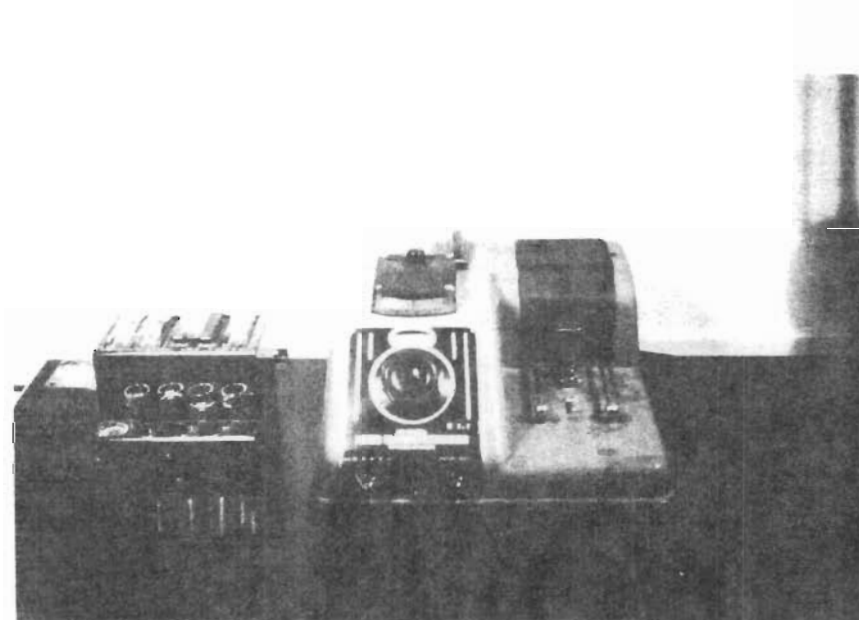


Figure 5. Electrophotometer for monitoring dye samples.



## II. FIELD EXPERIMENTS

A knowledge of the hydraulic conductivity and the slope of the groundwater table is a prerequisite to the intelligent application of a field tracer program. Without this information, planning the injection of the tracer and the subsequent times and places to take samples would be very difficult. Therefore preliminary tests to determine in-situ hydraulic conductivity and groundwater-table slope are very important before evaluating the feasibility, both economically and time-wise, of a tracer program. If the velocity calculated from hydraulic conductivity and hydraulic gradient is very low, the applicability of a tracer test would be questionable. However, a step-wise tracer program might be designed in which several short-distance tracer tests could be run from which an overall pattern of flow could be estimated.

The slope of the groundwater table can be determined quite easily by drilling at least three holes, in a triangular pattern and deep enough to penetrate the water table, and recording the groundwater elevation after the water level has reached equilibrium. The maximum gradient and the probable direction of groundwater flow can be found by plotting and interpreting this information.

### Hydraulic Conductivity

The auger-hole method, as illustrated in Figure 6, was used in determining field hydraulic conductivity. During the first phase of the field work, the slug-injection and bailed-well transmissibility tests (7) were used in an attempt to determine the hydraulic conductivity. Since transmissibility is the product of hydraulic conductivity,  $K$ , and aquifer thickness,  $b$ , and since the aquifer thickness,  $b$ , could not be determined in all cases, this approach was discontinued. However, it was discovered that the data collected for the transmissibility tests were, after slight rearrangement, sufficient to determine the hydraulic conductivity by the auger-hole method outlined by Winger (33). Therefore, all of the data were reworked using the auger-hole method of determining hydraulic conductivity. An example of the calculations is shown in Figure 60, Appendix B.

In some types of soil, the auger hole would not remain open unless casing was installed. The casing used was either 2-inch solid casing with a 2-foot drive wellpoint attached to the end, or 2-inch perforated aluminum casing. Hydraulic conductivity tests were run in some of the cased holes even though the assumptions for the auger-hole method were not completely satisfied. It was believed, but not proven, that a given diameter auger hole, cased with a smaller diameter wellpoint or perforated pipe, would fit a condition somewhere between that proposed in the auger-hole and the piezometer theory. The actual position would depend on how the surrounding soil behaved. It was expected that a correlation between the velocity determined by this method could be made with the velocity determined by the tracer method.

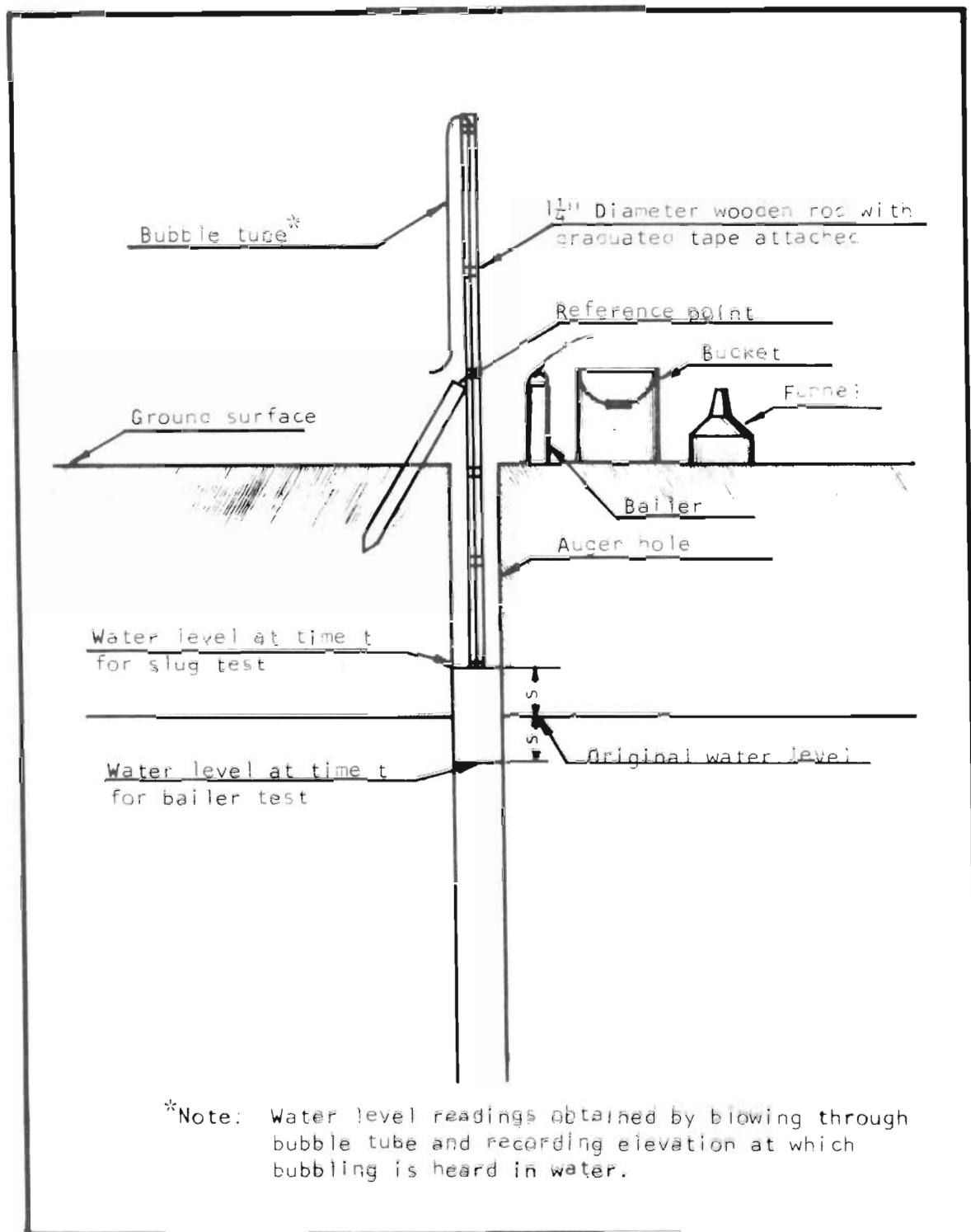


Figure 6. Details of equipment and the method for performing the auger-hole hydraulic conductivity test.

Type of soil. Sites that contained a wide variety of soils were selected for field experiments. A wide range of soils was classified including sandy clay, silty clay, silt, fine sand, and even a coarse sand. This range of soils was chosen, not because each soil would be present in all landslides, but if one of these soils was encountered, the practicality of running hydraulic conductivity tests in that particular soil should be understood.

Size of holes. To determine the effect of hole diameter and depth below the water table on the hydraulic conductivity, various diameter holes were drilled to penetrate the water table. After making several tests the holes were deepened and more tests were performed. Because of time limitations, only the Clyde Site was chosen for comprehensive tests of hole-size effect on hydraulic conductivity values.

Drilling Equipment. Most of the auger holes were drilled with the two-man, Acker, power auger as shown in Figure 7. Each flight of drill auger was 4 feet long and 3 inches in diameter. The Acker power drill is capable of being reversed in case the auger gets caught or stuck. This proved to be an important feature when drilling in areas where the soil mass contained either rubble or highly cohesive material.

Holes other than the 3-inch auger holes were drilled with hand augers, 2-inches, 4-inches, 6-inches, and 8-inches in diameter. In holes where sand or silty sand was encountered below the water table, the soil could not be retrieved with the hand augers. In these instances the two-man power auger or the Highway Department's truck-mounted power auger (Figure 8) was used to deepen the holes, and after withdrawal of the auger, a drive wellpoint on 2-inch casing, or a perforated 2-inch aluminum pipe was installed to maintain an open hole.

### Tracers

Dispersion. All tracer experiments are affected, to some extent, by dispersion of the tracer material as it is transported through the soil by the groundwater. Dispersion is caused by mechanical mixing and diffusion. Mechanical mixing occurs as the seepage paths along which a tracer material is being transported divide and combine with other seepage paths. This spreading of the tracer solution occurs transverse to the direction of flow. As the tracer solution contacts seepage water from other flow paths that contain lower concentrations of the tracer, diffusion occurs. Diffusion is considered to be the movement of the tracer by a concentration gradient. The amount of tracer necessary to trace groundwater movement is very dependent upon the amount of dispersion, both horizontal and vertical. Danel (5) proposed a six-degree dispersion cone, while Parson's field experiments (23) showed very little dispersion. Many other experiments with tracers have shown that dispersion does occur, but dispersion angles were rarely given.

The relationship between dispersion angle and the number of pounds of dye to produce a solution of 10 ppm concentration in a soil with 30 per cent porosity was calculated and is shown in Figure 9. The importance



Figure 7. Two-man power auger in operation.



Figure 8. Truck-mounted power auger in operation.

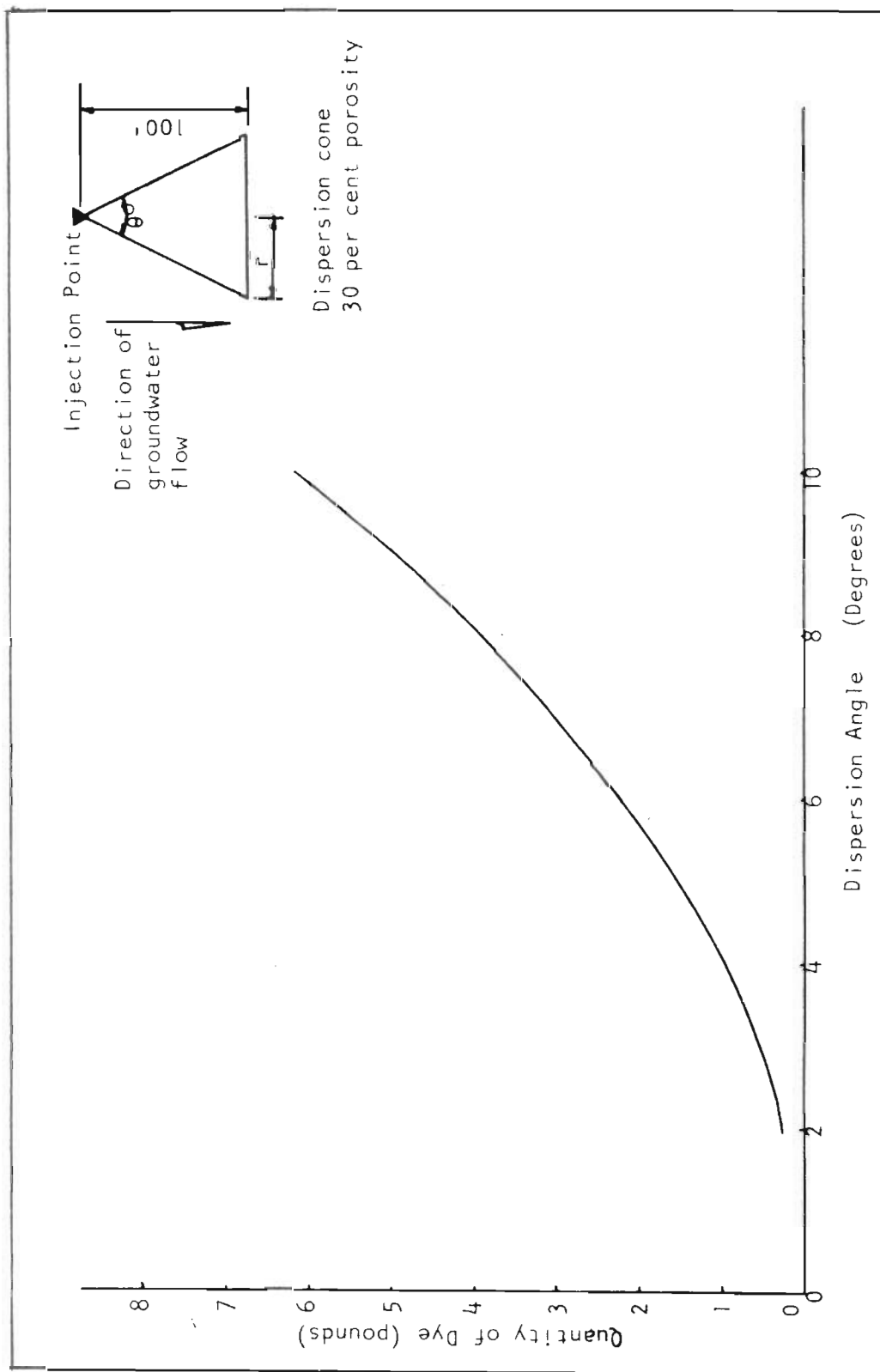


Figure 9. Relation between pounds of dye to produce 10 ppm concentration and dispersion angle in degrees.

of knowing the dispersion angle is recognized when a comparison is made between the two-degree and the ten-degree dispersion angle. It takes only 0.24 pounds of dye for the two-degree angle, but it takes 6.10 pounds of dye for the ten-degree angle to produce the same concentration of dye in the groundwater circumscribed by the dispersion cone.

Comparison of various types of tracers. An attempt was made to compare the effectiveness of the several tracer materials in several different soils in situ. Experiments were run at some of the sites in which different tracers were identically prepared, injected, and sampled. The analyses were necessarily different for the different types of dyes. Fluorescein, pontacyl, rhodamine, FD&C Red #2, and tritium were compared under field conditions. The Hoodoo Valley, Clyde, Brammer, Robinson, and Lolo Sites were chosen for very detailed comparisons of tracers. The hole patterns were different at each site because of the site layout, problems encountered in drilling, and availability of previously drilled holes.

Injection. There are two common methods of introducing a tracer material into the groundwater system: (1) the tracer material in its concentrated form can be injected, or (2) the tracer material can be put into solution and injected. A solution injection can be made as a slug by putting in a large quantity of solution in the injection hole at one time, or as a continuous injection by allowing a continuous flow of the solution into the injection hole for a given period of time.

Both methods of injection were used in the field experiments. The injected concentration ranged from a solution of 200 ppm to the original concentrated tracer. The amount of dye tracer injected either in solution or in its concentrated form never exceeded one pound for any single injection. At times, two tracer materials were dissolved or mixed into one solution and injected into an injection hole. In most cases the tracer or tracer solution was injected into a cased or uncased hole that penetrated the water table. Mixing of the tracer solution with the native water was accomplished by pouring small quantities of the native water into the injection hole to agitate and force the tracer solution out of the hole into the surrounding soil-water system. At two sites, the tracer was placed into injection trenches from which rain water carried the tracer into the soil and down to the groundwater table.

Sampling. The sampling equipment used for this investigation consisted of a bailer, and a selective-depth sampler as shown in Figure 10. Water samples were taken from the cased and uncased holes with the sampler and then were transferred to small glass containers for transporting to the laboratory. The bailer was used for most of the sampling, and the procedure was: (1) the bailer was thoroughly cleaned and rinsed, (2) several (three to five) bailers of water were withdrawn from the hole to assure that if the tracer was near the hole it would enter and be sampled, (3) a water sample was placed in the small glass container, and (4) the bailer was again rinsed before sampling at the next hole.

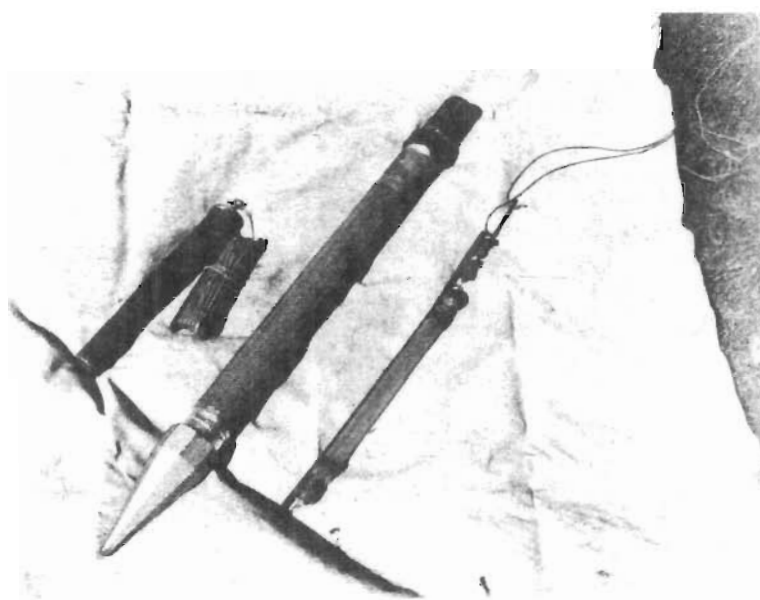


Figure 10. Equipment consisting of (from left to right) a bailer, a 2-inch drive wellpoint, and a selective depth sampler.

Contamination. Many ways exist for contaminating equipment when working in a tracer program. Wellpoints and casing, if in contact with dyes, can adsorb the dye. A sampler can transfer dye from one sample hole to another. The sample containers, if not thoroughly cleaned, can cause erroneous readings. The investigator can inadvertently contaminate samples by dye on his hands or on his clothing.

Many of the dyes are handled in powder form which creates the possibility of this powder being scattered by even a small breeze. The dye in powdered form is hard to see and the contamination may go unnoticed until contact with water is made. Sample holes, equipment, and the investigator can be contaminated by this process.

The fact that contamination can and does occur should cause the investigator to plan the program with utmost care and to always be aware of the possibility of contamination as the program is carried out. Special care should be taken to prepare dye solutions in the laboratory so that powdered dye need not be taken to the field. Precautions should be taken to clean the glass sample containers very thoroughly. Plastic containers should not be reused because the pores within the plastic are very difficult to clean.

Certain acids have been reported to neutralize the fluorescence of some dyes. This may be a means of solving at least part of the contamination problem.

Effect on hydraulic conductivity. Because some of the tracer materials were likely to influence the hydraulic conductivity, tests were performed to determine the extent to which tracers may cause "plugging" in the soil pores or a reduction of available flow space. Since initial laboratory testing showed that fluorescein was less apt to cause "plugging" than other dyes, it was chosen for further "plugging" tests, believing that if it tended to "plug" soil pores, then certainly the other dyes would be expected to do likewise and to a greater extent. The further experimenting was performed by running hydraulic conductivity tests after various quantities of a tracer solution had been injected into a hole. After a definite decrease in the hydraulic conductivity was evident, a bailing of tracer solution from the hole was performed to examine the possibility of "unplugging" the pore passages. Then additional hydraulic conductivity tests were run.



## CHAPTER IV

### RESULTS

#### I. LABORATORY EXPERIMENTS

Laboratory test results showed that many of the dyes would not be suitable for tracing water movement in any except coarse-grained soils. Other dyes would be useful in tracing water even in fine-grained soils such as the Palouse loess.

The dyes, FD&C Violet #1, gentian violet, porirriers blue, methyl blue, and rhodamine, were unsatisfactory for tracing water in fine-grained soils because they were filtered or adsorbed out of the water within very short distances. This is evident by comparing the depth of dye penetration between these dyes and pontacyl in Figure 11 which shows the top section of the soil columns. The soil was a very highly compacted loess which retained the dyes, with the exception of pontacyl, within the top 1/4 inch.

Figure 12 shows a typical comparison between the four dyes considered to have the best chances of tracing water through soil. The soil samples were Palouse loess lightly compacted in three layers, making 8-inch long soil columns. Movement of the dyes was evident in the soil columns, but rhodamine advanced slightly less than one half the length of the soil column while the other dyes penetrated the entire length. After the soil columns had drained more completely, they were vertically sliced for comparison as shown in Figure 13. The soil columns for the fluorescein solution did not show any retention of fluorescein while the soil column that the pontacyl solution was passed through showed a slight reddish color due to retention of the pontacyl. The soil column for the rhodamine solution showed that nearly all of the rhodamine was retained in the upper 4 to 5 inches of the soil column. The other soil column that the solution of FD&C Red #2 was passed through crumbled upon slicing; however, it showed results similar to pontacyl.

All of the laboratory tests involving many different soils, placed in soil columns with different compactive efforts, showed that fluorescein, pontacyl, and FD&C Red #2 were less adsorbed or filtered out than the other dyes and would therefore be more applicable to tracing groundwater. Fluorescein and FD&C Red #2 appeared to be slightly superior to pontacyl for tracing groundwater in that they moved with the water and were less adsorbed than pontacyl. But detection of FD&C #2 is made with the electrophotometer which is not capable of detecting as low a concentration as the fluorometer which is used in detection of pontacyl and fluorescein.

Quantitative results of the adsorption or filtration of fluorescein, pontacyl, FD&C #2, and rhodamine showed that only a certain per

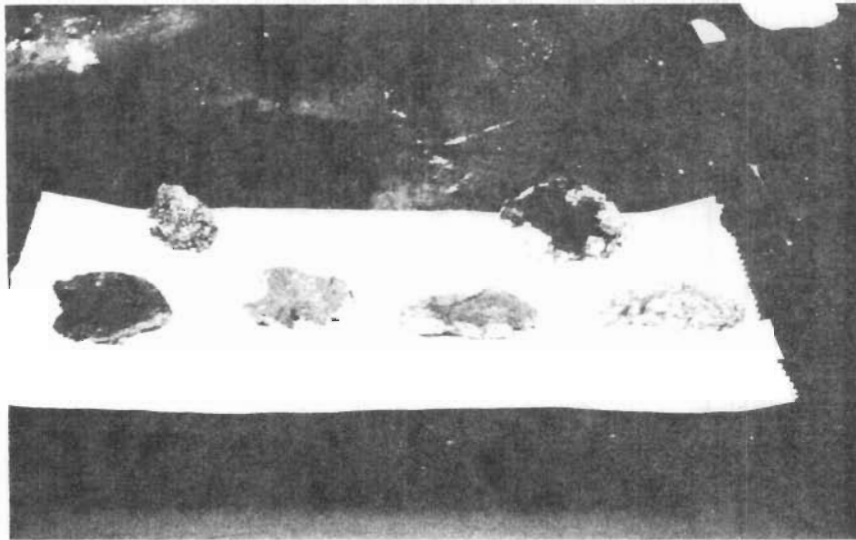


Figure 11. Comparison of dye penetration.

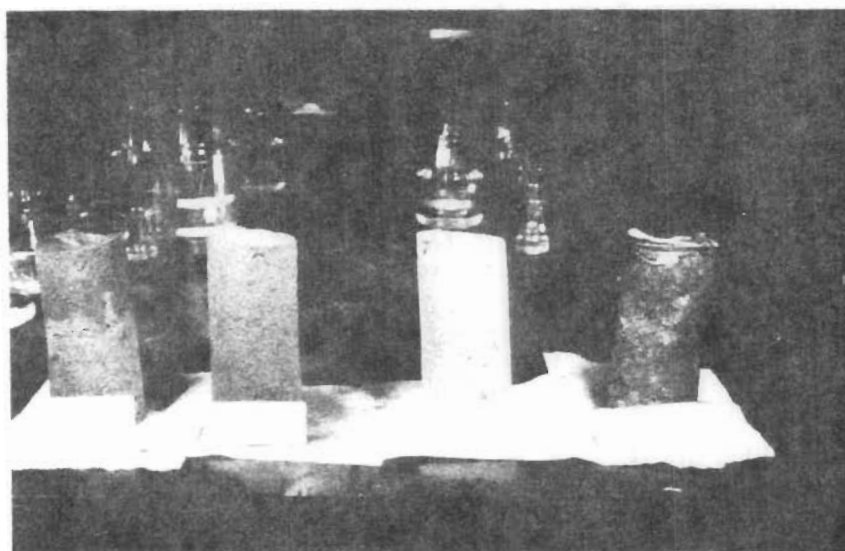


Figure 12. Comparison of dye retention.



Figure 13. Sliced soil columns depicting dye retention.

cent of the dye passed completely through the soil column even after large quantities of distilled water had been used to rinse the soil columns. Values of per cent passing completely through the columns ranged from less than 10 per cent to slightly more than 90 per cent. For different soils and different dyes these values varied, but again, concentration readings of fluorescein, FD&C Red #2, pontacyl, and rhodamine, respectively, showed decreasing values of dye passing completely through the soil columns.

Typical curves depicting how the concentration ratio varied with time are presented in Figure 14. The concentration ratio is the ratio of the concentration of dye remaining in solution after having passed through the soil columns to the concentration of the original solution. Information for these curves was obtained by passing 100 milliliters of 100 ppm of each dye through an 8-inch long, 4-inch diameter soil column. The steps were: (1) the soil column was saturated with distilled water, (2) the dye solution was poured onto the top of the soil column, (3) after the solution had entered the soil, distilled water was used to maintain a constant 2-inch depth above the soil surface, (4) all of the seepage solution was collected after it had flowed through the soil column, and (5) dye concentrations were determined by fluorometric or electrophotometric readings. The concentration of the dyes built up to a peak and then decreased for many hours. However, low concentrations of the dyes were still present in the exiting solutions when the tests were discontinued after as long as 600 hours.

Chelating agents, "blue cheer" and "tetrasodiumpyrophosphate", were tested to determine if their presence in the dye solution would aid the dye to follow the water movement. "Blue cheer" served to keep the dye in solution better than when no chelating agent was used, but it also tended to slow the movement. The effect of "tetrasodiumpyrophosphate" on the water movement through the soil was negligible.

Information gained from the laboratory experiments was used in planning many of the field investigations.

## II. FIELD EXPERIMENTS

Initially, sites were selected in areas of known groundwater movement so that tracer studies could be inaugurated with a minimum of unknown parameters. It was desirable, also, to have many different soil types included in the preliminary tests. After preliminary testing at certain sites had been performed, areas containing actual landslide problems, either potential or active, were selected for further tests. Figure 15 shows the location of all field sites chosen for detailed tests.

### Fleiger Site

The Fleiger Site was located on a flood plain bordering the South Fork of the Palouse River about one mile south of Moscow in the NE1/4 sec. 19, T. 39 N., R. 5 W., on property owned by Richard R. Fleiger. An aquifer of well-graded sand was present with a water table between 3 to 7 feet from the ground surface. The aquifer was thought to be fairly homogeneous. Figure 58, Appendix A, shows a typical soil profile and gives properties of the sand.

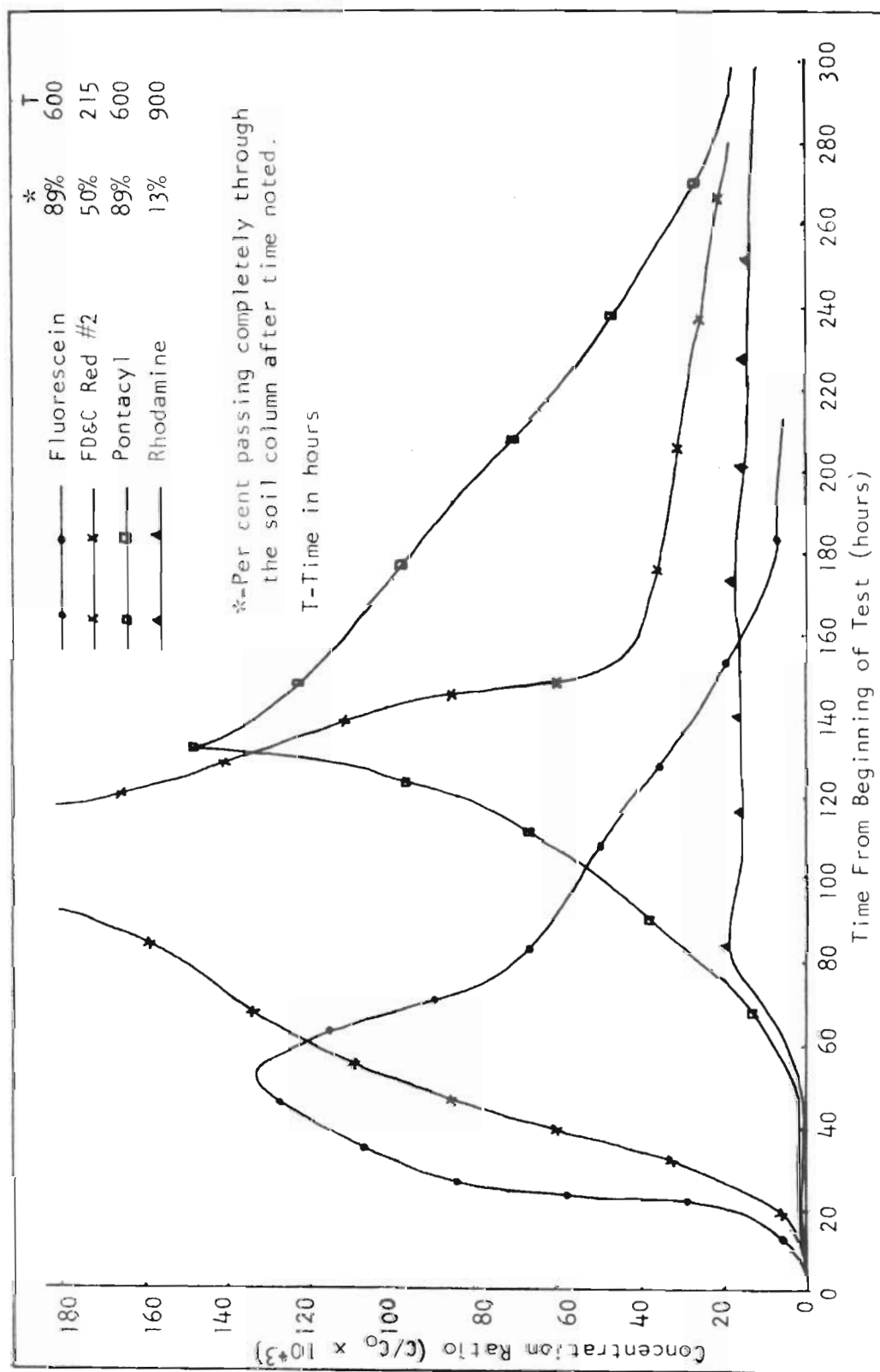


Figure 14. Concentration ratio of dye solutions passed through soil columns versus time. See text for explanation.

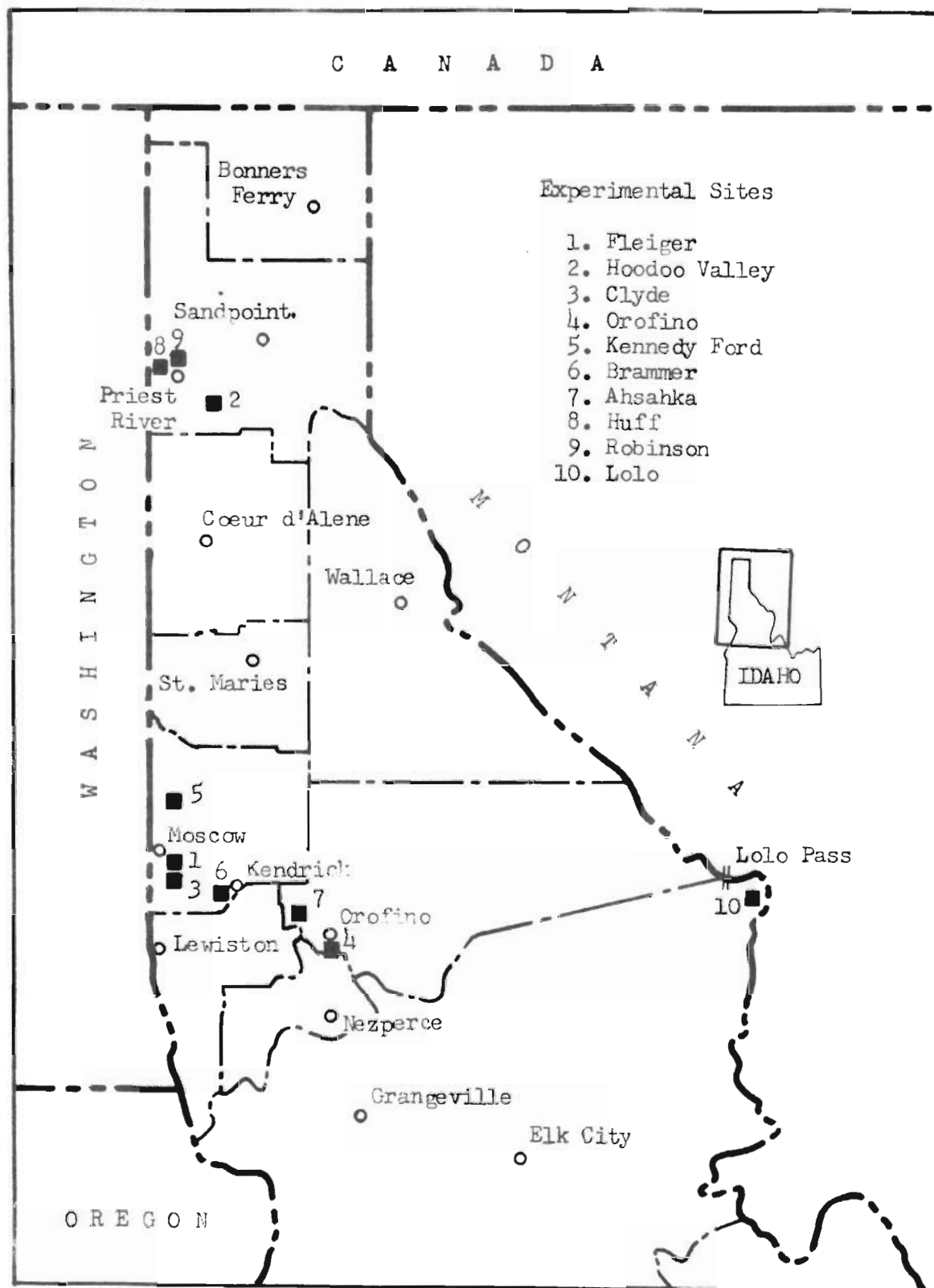


Figure 15. Map showing locations of experimental sites.

A few preliminary hydraulic conductivity tests were made so that the values could be used in conjunction with the hydraulic gradient to determine the probable direction and velocity of groundwater movement. Patterns of holes were drilled with the two-man, Acker, power auger, and cased with 2-inch casing with a 2-foot drive wellpoint attached. The hole patterns were determined by fixing the location of the injection hole and then locating sample holes fanned out along the assumed direction of flow, down-gradient from the injection hole. Because the gradient of the water table was very flat ( $S = 0.0027$ ), the calculated superficial velocity was extremely low. Therefore, one pattern of holes was drilled symmetrically about the injection hole as shown in Figure 16.

The symmetrical pattern was used for groundwater fluctuation and tracer tests by injecting Moscow tap water at a constant 6-foot head above the original water table for four hours. Water-table readings were recorded at the surrounding holes every 15 minutes. Other tests, to determine the "plugging" action of fluorescein dye on the soil pores were run by injecting a solution of 200 ppm fluorescein into the injection hole. Hydraulic conductivity tests were made at intervals when 0, 40, 80, and 120 gallons of dye solution had been injected. Fluorescein and pontacyl dye were injected individually in other patterns to learn which material would be the most suitable as a tracer for use in the particular type of soil that underlaid the site.

The effect of the hole size on the hydraulic conductivity was investigated by drilling 2-inch, 3-inch, 4-inch, 6-inch, and 8-inch diameter holes deep enough to just penetrate the aquifer. Hydraulic conductivity tests were run on these different diameter holes and also on some other cased and uncased holes.

The results of the tracer tests were very inconclusive. Visual detection of the tracer, fluorescein, was made at holes 4NE, 4SE, and 8NE of the symmetrical pattern. Fluorometric detection was made in holes 4NW and 4SW, but at much lower concentrations than in the holes where detection was made visually. This information together with the fluctuation of the water table showed that, with the artificial groundwater gradient, the water moved more rapidly in the easterly direction than in the westerly direction. This was a direct contradiction to the direction estimated from the original water-table gradient. This can be explained by noting that when the holes were drilled for this test the westerly holes had more silt and clay interspersed with the sand than did the easterly holes and therefore, the permeability would be less and the velocity would be slower to the west than to the east.

Hydraulic conductivity values by the auger-hole method varied over a wide range, from 0.1 to 8.0 feet per day with an average of 2.7 feet per day. The reasons for this variation were: (1) non-uniform hole diameters due to caving, (2) tests performed in cased holes did not conform with the assumptions of the test method, and (3) the soil was not homogeneous. The effect of the hole diameter on hydraulic conductivity was inconclusive.

A definite effect on the transmissibility of the aquifer was caused by injecting the fluorescein dye solution. Figure 19 shows that after 120

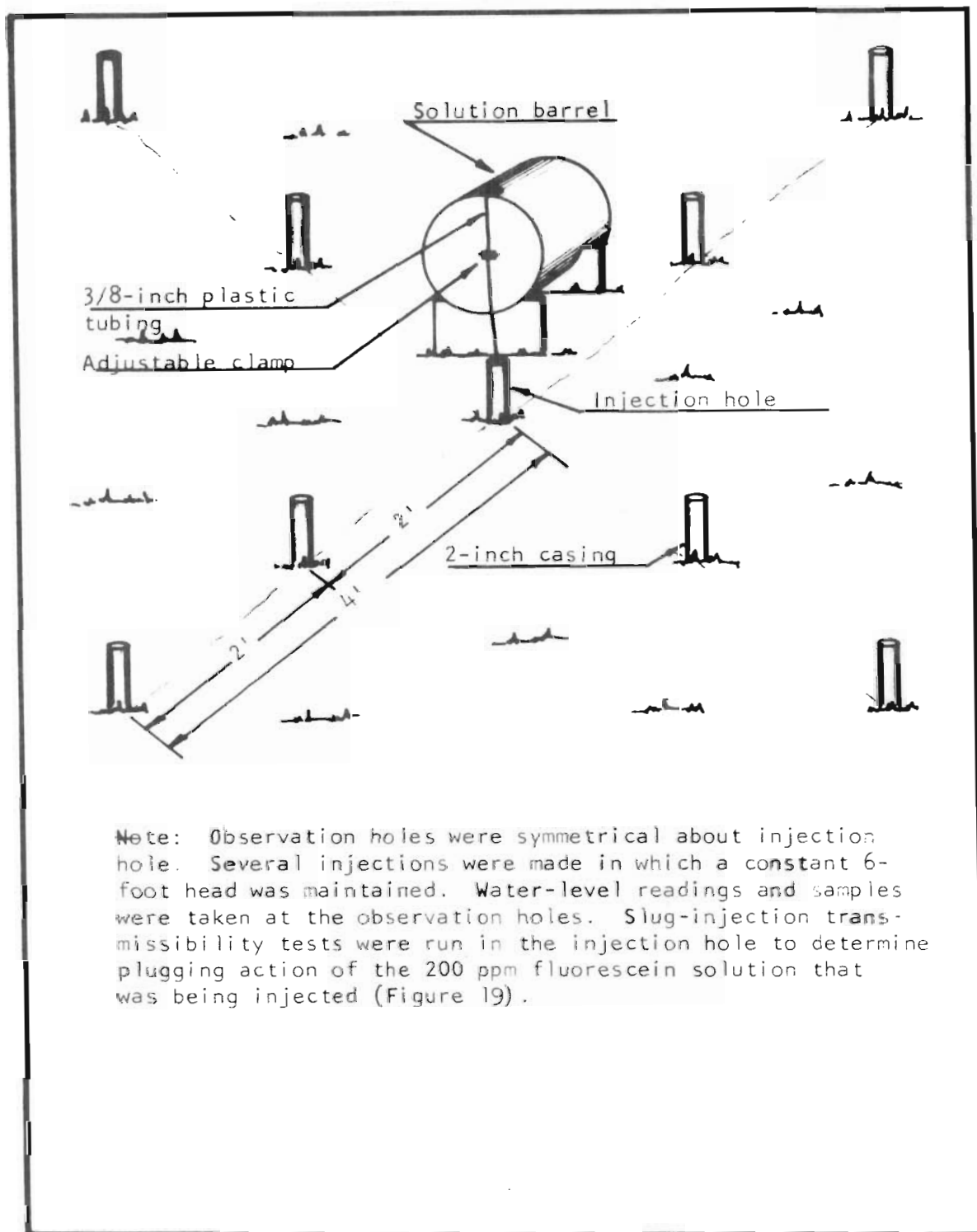


Figure 16. Layout and equipment for special water-table and dye plugging studies.



gallons of 200 ppm fluorescein solution was injected, the transmissibility was only about one-third of the value before dye injection began.

#### Hoodoo Valley Site

A site was chosen in Hoodoo Valley that was underlain by a confined aquifer of clean, fine sand. It was located 8 miles southeast of Priest River in the SE1/4 sec. 12, T. 55 N., R. 4 W., on the Jolley property. The soil profile is shown, and the gradation of the sand is given, in Figure 58, Appendix A. The piezometric surface, the elevation to which the groundwater would rise if not confined, was about 1 foot above the upper confining bed or about 2 feet below the ground surface.

The auger-hole test for hydraulic conductivity was not applicable to a confined aquifer, and furthermore, an uncased hole would not remain open in the sand. Therefore, the bailed-well test for determining transmissibility was used for this area (Figure 17). The aquifer thickness,  $b$ , was estimated from drilling information.

After the direction and velocity of groundwater movement had been calculated, patterns of holes were drilled and cased for tracer tests as shown in Figure 18. Extensive tests were run on plot one with fluorescein as the tracer material. Prolonged bailing from sample holes was performed simultaneously with maintaining a head on the injection hole in order to increase the gradient of the water table between the holes. Tests to study the "plugging" action of fluorescein dye were run by injecting large quantities of concentrated fluorescein solution and determining its effect on transmissibility. Intermediate bailing was conducted to determine if "unplugging" could be accomplished.

Tracer tests on plots two, three, and four were conducted differently from those on plot one, in that care was taken to limit the amount of injected solution so as not to disturb the water-table slope any more than necessary. Fluorescein, pontacyl, and rhodamine in concentrations of approximately 2000 ppm were injected in separate plots by pouring into the injection holes about 50 ml, each 15 to 30 minutes, until a 300 ml injection had been accomplished. This was done once each week for three consecutive weeks. Samples were taken over a period of about 14 weeks.

The bailed-well and slug-injection transmissibility tests and the hydraulic gradient determinations resulted in the following:

$$T = 30 \frac{\text{ft/day}}{\text{ft}}$$

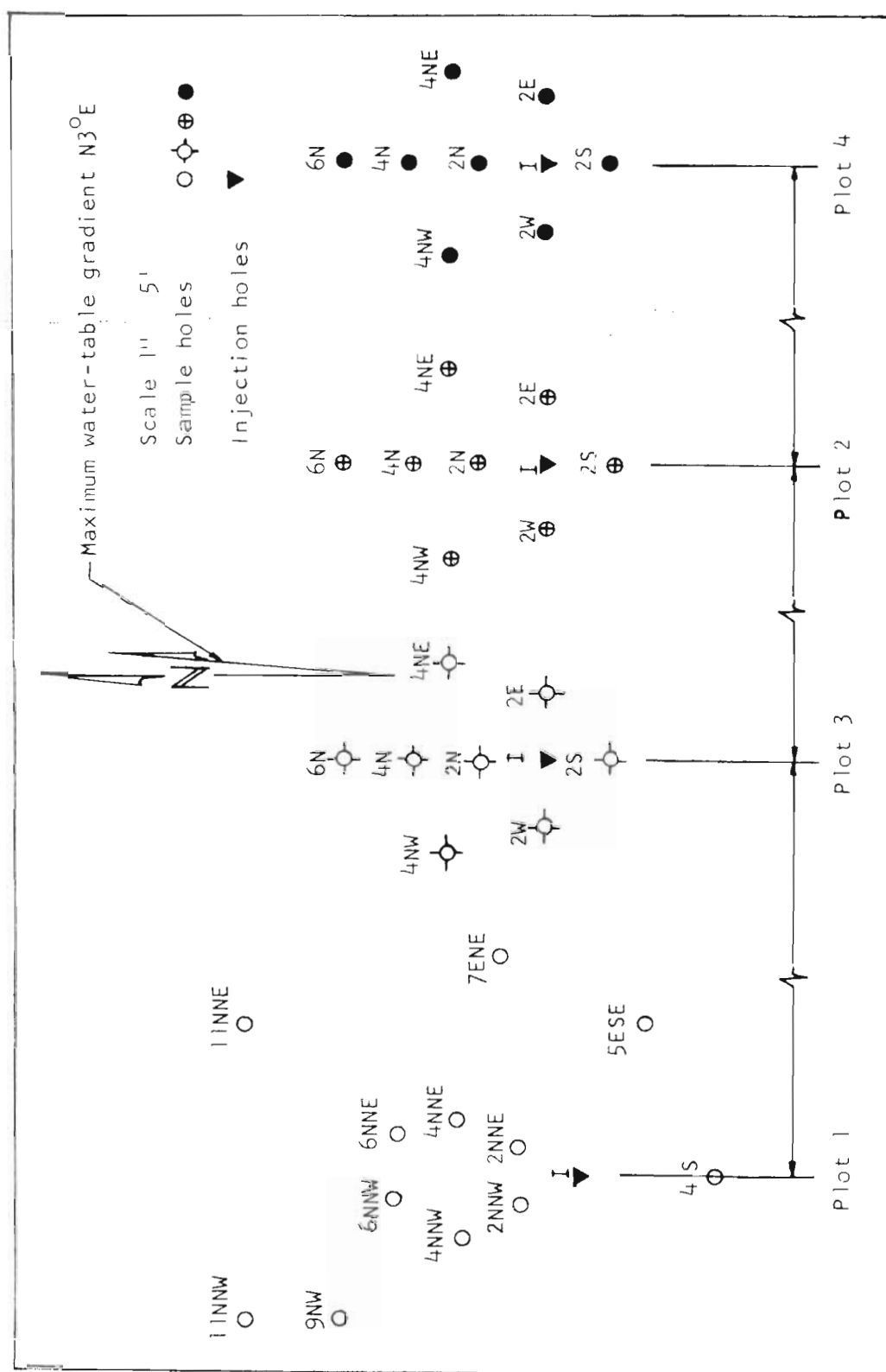
$$K = \frac{T}{b} = \frac{30}{5} = 6 \frac{\text{ft}}{\text{day}}$$

$$V = K i = (6) (.0035) = .021 \text{ ft/day}$$

$$V_s = \frac{V}{N} = \frac{.021}{.30} = .07 \text{ ft/day}$$



Figure 17. Conducting transmissibility tests.  
(Hoodoo Valley Site)



in which

$T$  = transmissibility

$K$  = hydraulic conductivity

$b$  = aquifer thickness

$V$  = superficial velocity

$V_s$  = seepage velocity

$N$  = porosity (estimated)

"Plugging" of the soil pores occurred quite rapidly because of the high concentration of dye injected (Figure 19). Upon bailing, the transmissibility values increased rapidly to a value higher than the original value because of (1) "unplugging" of soil pores, and (2) possibly better development of the hole. It was noted that, although part of the "plugging" action occurred at the wellpoint screen, most of it occurred in the soil passages.

In plots three and four there was no detection of tracer movement between the injection hole and any of the sample holes except possibly 2N of plot four. In plot one, fluorescein dye was visually detected as far as 8 feet north of the injection hole.

Fluorometric readings at holes of plot one were very sporadic as shown in Figure 20. Hole 11 NNW shows results similar to those of hole 11 NNE although the concentration peaks are slightly lagging in time. The peak points of concentration of these two holes were caused from contamination due to heavy rains flooding the injection hole and some other holes. The reason for the lower peaking and the lagging of hole 11 NNW was that contaminated water did not enter directly into this hole as it did in hole 11 NNE, but instead it seeped through soil for a short distance. During the first 30 days of experiments at plot one the fluorometer was not available for tracer detection, hence the gap from the first injection to the first fluorometric readings.

Improper sampling procedures, contaminated sample containers, and contaminated wellpoints and casing caused faulty fluorometric readings during the early tracer tests in both plots one and two. The fluorometric readings shown in Figures 20 and 21 substantiate this. Examination of the erratic readings near the beginning of the tests shows a downward leveling trend of the readings for most of the holes.

Figure 21 shows that tracer movement did occur between the injection hole and hole 2N of plot two with a travel time of about 20 days. This would indicate a velocity of about 0.1 foot per day which compares quite well with the calculated seepage velocity of 0.07 foot per day. Plots three and four did not yield results to show that any movement of tracer occurred.

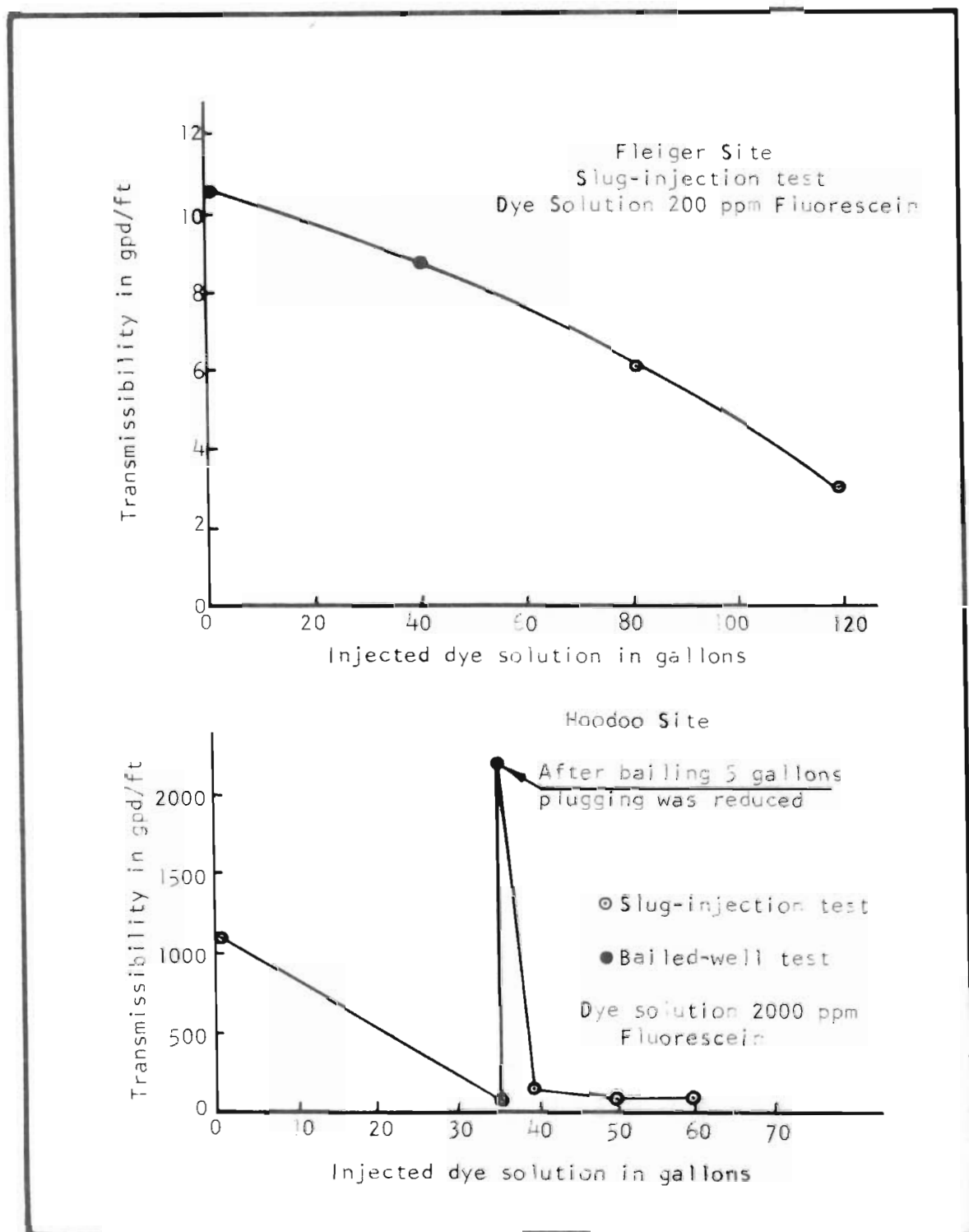


Figure 19. Relationship between dye-injection plugging action and transmissibility values.

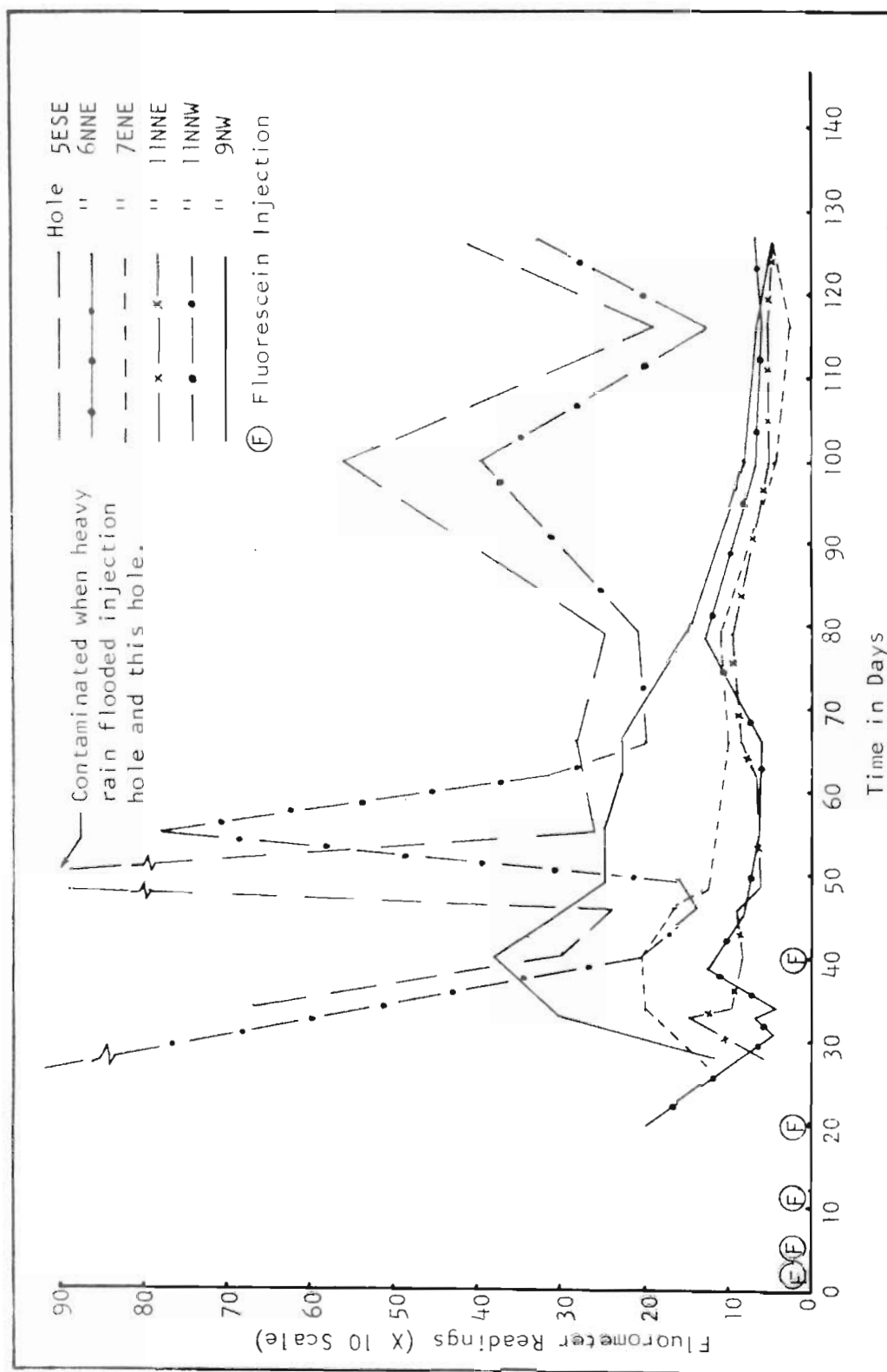


Figure 20. Relative dye concentrations at sample holes versus time since injection of dye (Hoodoo Valley Site).

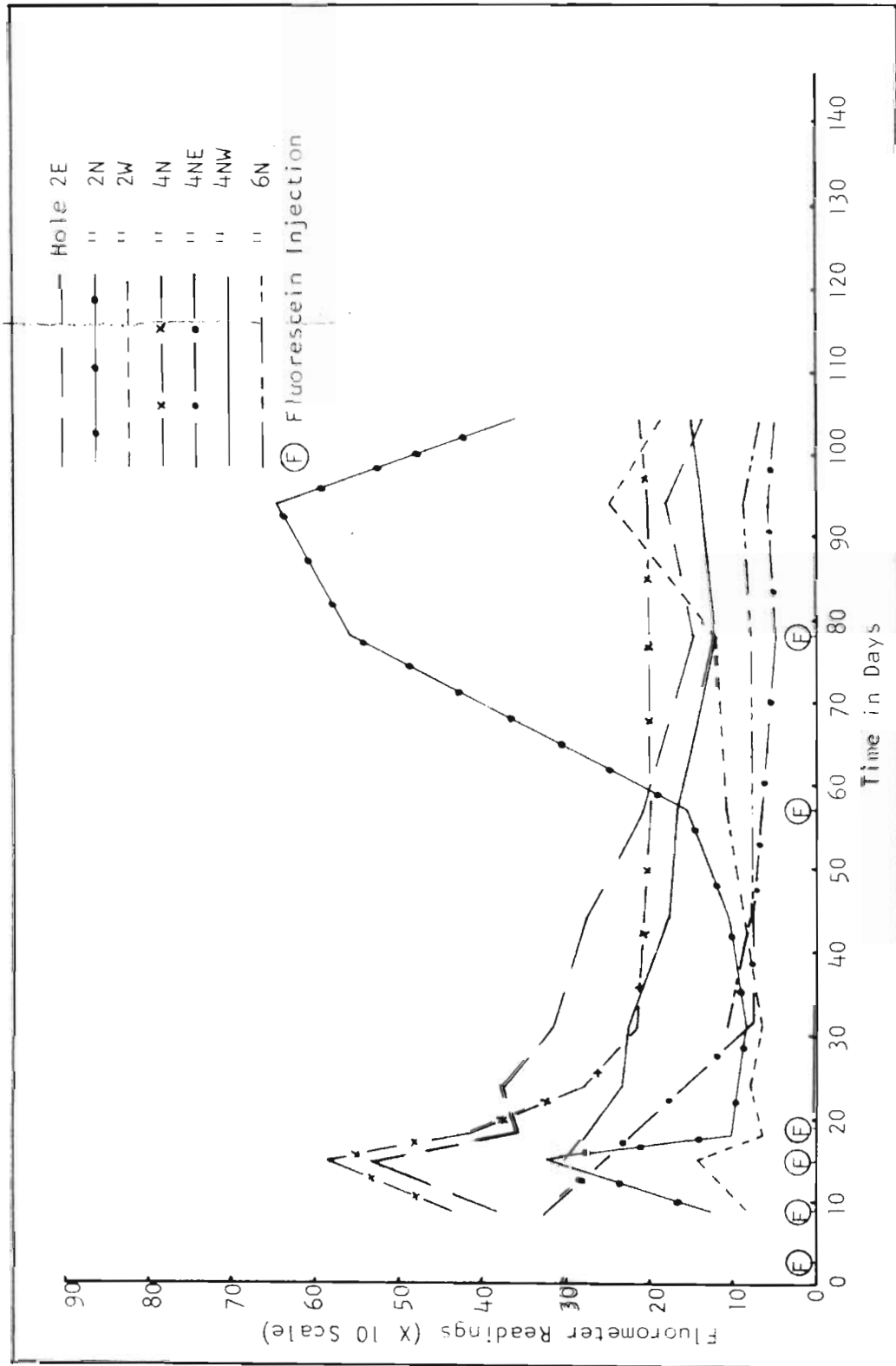


Figure 21. Relative dye concentrations at sample holes versus time since injection of dye (Hoodoo Valley Site).

### Clyde Site

The Clyde Site was located 4 miles south of Moscow in the SE1/4 sec. 31, T. 39 N., R. 5 W., on property owned by Earl H. Clyde. This site was chosen for three reasons:

1. The soil was different from that of other sites.
2. Hydraulic conductivity tests could be run using the auger-hole method.
3. The site was available year-round.

After preliminary hydraulic conductivity tests had been performed and the groundwater slope established, patterns of holes were drilled as shown in Figure 22, Figure 58, Appendix A, shows a typical soil profile and some soil properties.

The dyes, rhodamine, fluorescein, and pontacyl, were injected in separate holes. A combination of fluorescein and pontacyl was injected into a fourth hole. The injected solution in all cases was 200 ml at 1000 ppm. Injections were made on December 8, 10, 14, and 24, 1964.

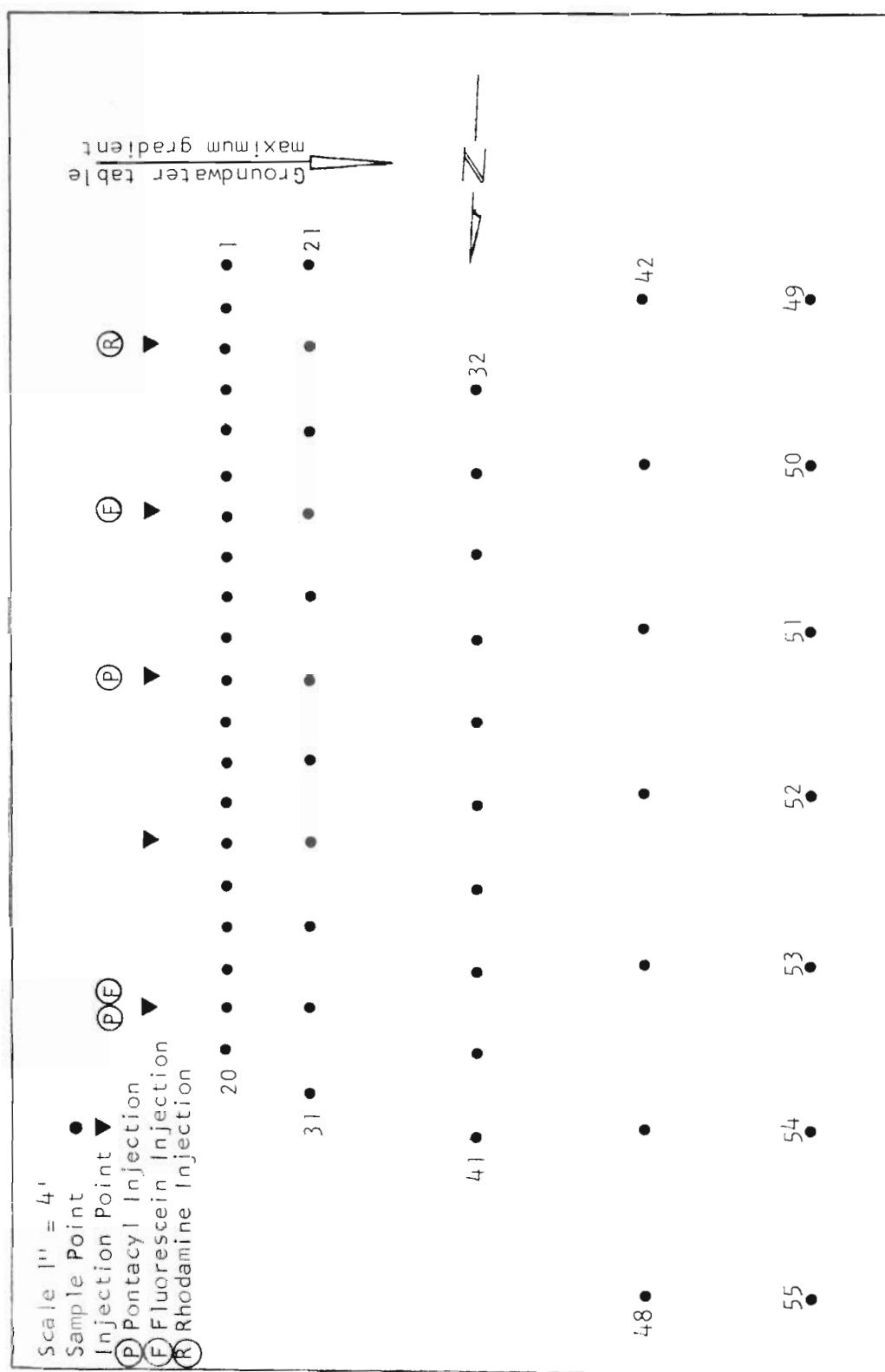
The effect that hole diameter and depth of hole below the water table had on hydraulic conductivity was studied by running tests on five different diameter holes at two different depths below the water level. The holes were first drilled to penetrate the water table by 1/2-foot and hydraulic conductivity tests were run. Then the holes were deepened to penetrate the water table by 2 1/2-feet and more hydraulic conductivity tests were run.

Since the same method and data can be used for the auger-hole hydraulic conductivity test and the slug-injection or bailed-well transmissibility tests, the results of both tests are shown in Figure 23 for comparison. The range of values for the hydraulic conductivity test was very narrow. The diameter and depth of hole did not seem to influence the hydraulic conductivity values substantially. The average of all hydraulic conductivity tests was 7.2 feet per day which when multiplied by the hydraulic gradient and modified by the estimated porosity, yielded a seepage velocity of about 1/2 foot per day. The diameter and depth of hole did influence the transmissibility values as shown by the wide range, from 150 to 700 gallons per day per foot, in Figure 23.

For the rhodamine injection (Figure 24) dye was detected at hole 3, 20 days from the first injection, but since no repeating cycle was evident for the other injections, the value of this peak point is questionable. The readings at other sample holes were sporadic, showing no trend or cycle that could be interpreted.

For the combined fluorescein and pontacyl injection, the results are shown in Figures 25 and 26. Detection of both dyes at holes 19 and 20 occurred very soon after the injection was made indicating the possibility of rodent holes interconnecting the injection and sampling holes; this was noticeable especially for hole 20. Field mice were prevalent in the area and many rodent holes were evident.





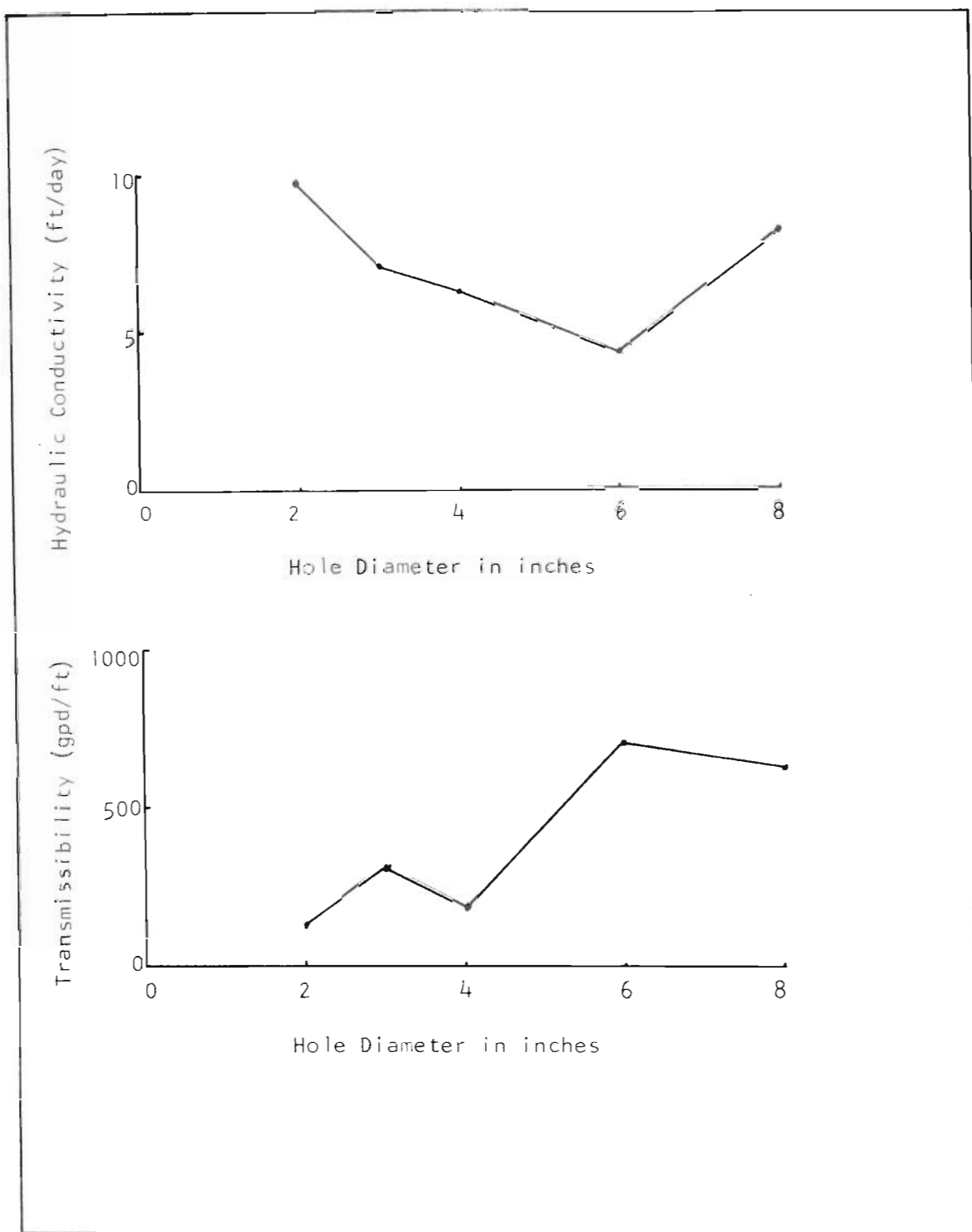


Figure 23. Relationship between hole diameter and calculated transmissibility and hydraulic conductivity (Clyde Site).

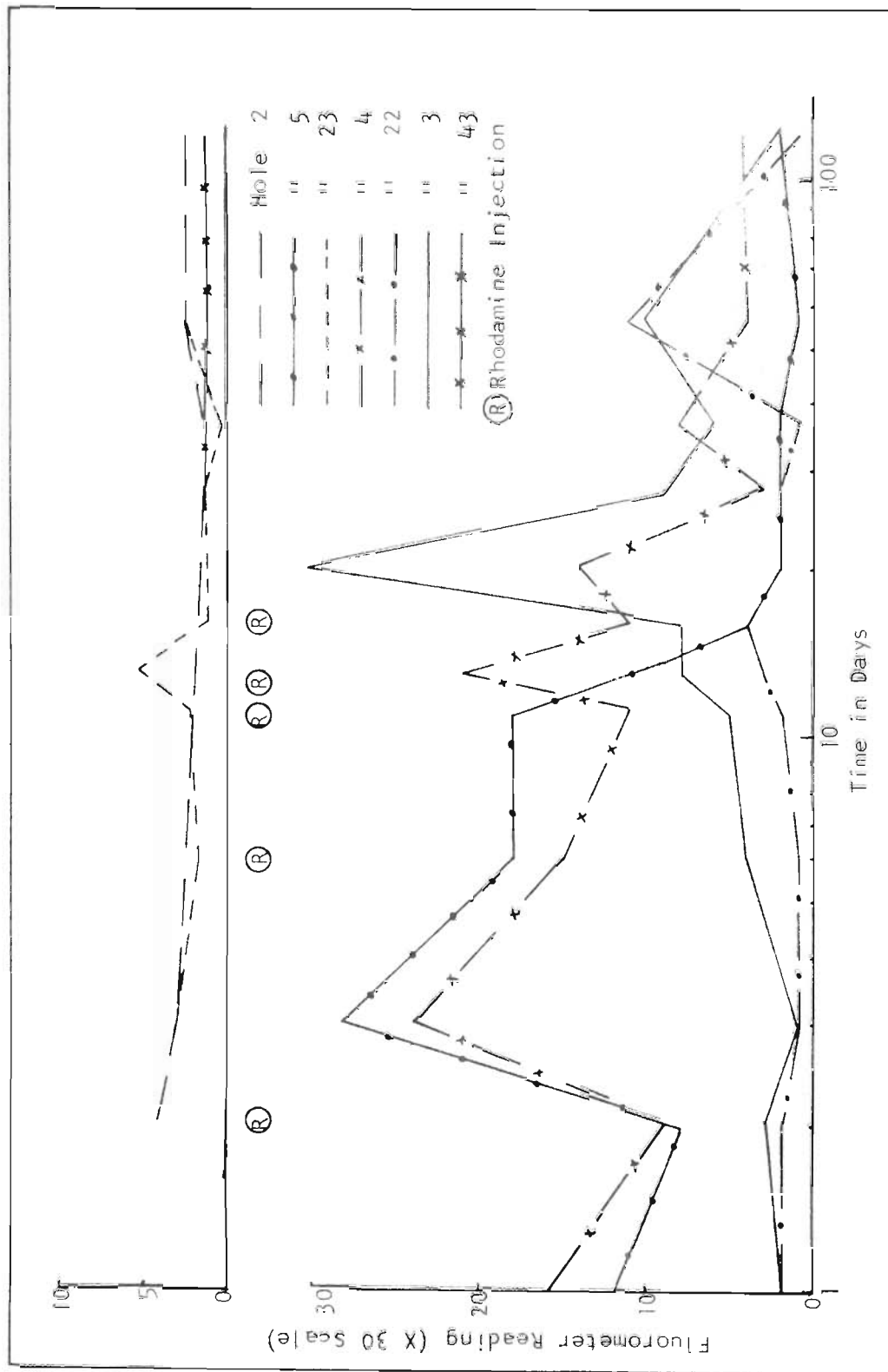


Figure 24. Relative dye concentrations at sample holes versus time since injection of dye (Clyde Site).

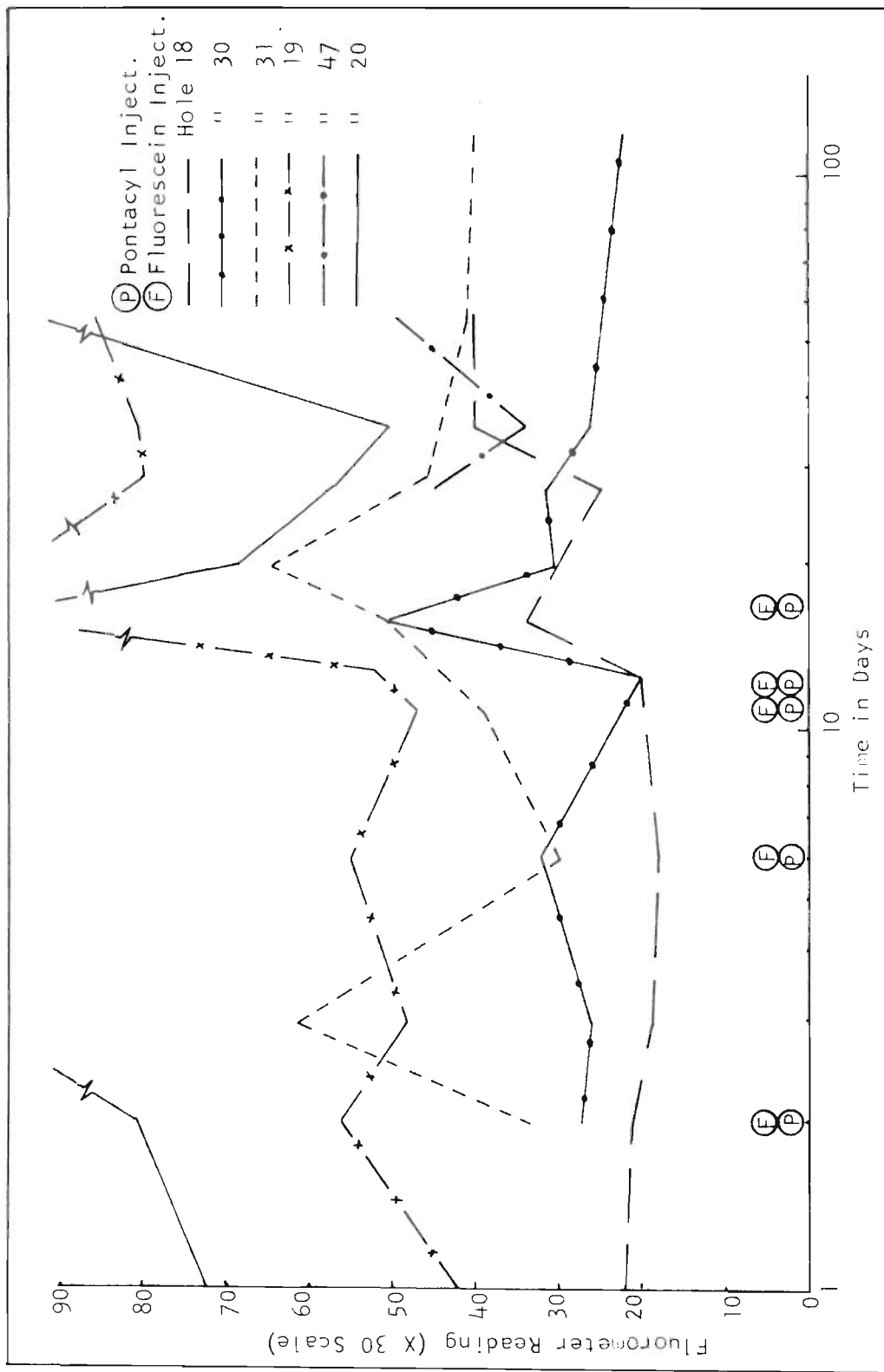


Figure 25. Relative dye concentrations at sample holes versus time since injection of dye (Clyde Site).

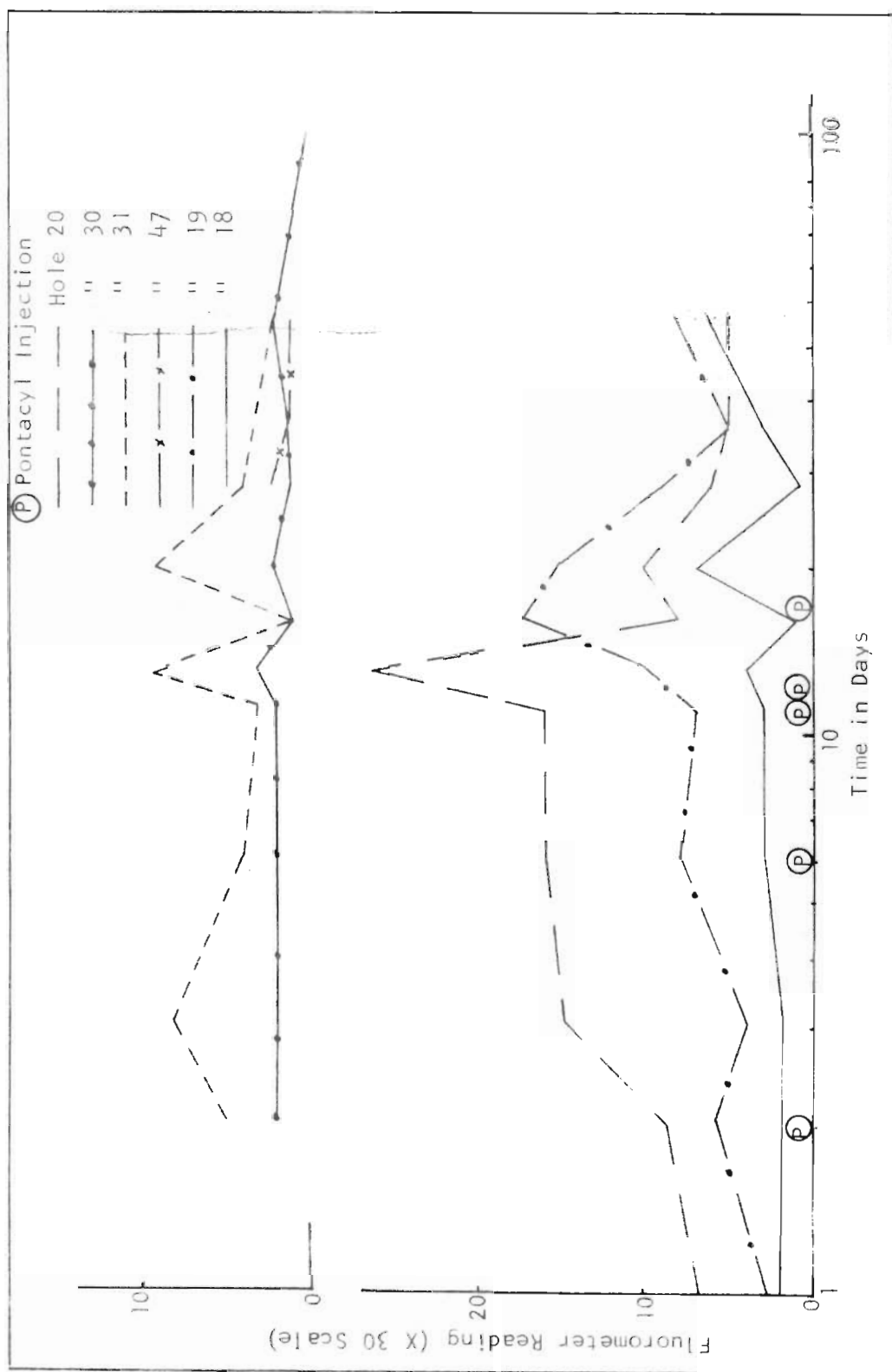


Figure 26. Relative dye concentrations at sample holes versus time since injection of dye (Clyde Site).

Figures 25, 27, and 28 show that nearly all samples collected 16 days after the initial injection gave a great increase in dye concentration. This increase is unexplainable as far as the tracer program is concerned, but it was noted that a heavy rainfall occurred just prior to and during this period. The way in which this rainfall affected the samples to give such high readings is not understood. Although some overland flow of rain water did occur, the site was not believed to have been flooded, and therefore cross contamination from the injection holes to the sampling points probably did not occur.

#### Orofino Site

The Orofino Site was located 1/2 mile southwest of Orofino in the SW1/4 sec. 7, T. 36 N., R. 2 E., on state highway right-of-way. It is part of an old slide area which is still showing slight movement. Since a new section of proposed highway would cut through the lower part of the slide, the Department of Highways drilled holes to determine the geology and water table, and to collect soil samples for laboratory analyses. Figure 29 shows a map of the site. The logs and soil data, which are presented in Figure 59, Appendix A, show the area to be underlain by rubble intermixed with silt and silty clay with a few sand lenses present. The sand lenses were thought to be the principal water-bearing material.

Stability analyses indicated that control of the groundwater elevation in the slide area was of vital importance if stability was to be maintained. Such information as velocity and direction of water movement, fluctuation of the water table, and hydraulic conductivity of the underlying soils was important before undertaking the design of a drainage system. An attempt to determine the required information was made by initiating a tracer program and by keeping a record of the water table elevations (See Table I, Appendix A).

Fluorescein and pontacyl dyes were injected in hole 6A, hole 11A, and trench II in quantities of 50 to 200 grams at a time. Samples were collected and analyzed. Pontacyl was detected, as shown in Figure 30, at hole 8A, 70 days after the first injection and 80 days after the second injection. A peak concentration was detected at sampling point cut No. 1, 104 days after injection at hole 11A. Figure 31 shows that no definite peak was established at hole 8A when fluorescein was used, but a high concentration was detected at cut No. 1, 104 days after injection of fluorescein in the injection trench. The distance was about 105 feet. As evident in Figure 32, fluorescein tracer was detected in hole 7A, about 41 feet from the injection hole 6A, in 14 days. A later injection of pontacyl was detected in hole 7A at 12 days. One hydraulic conductivity test was run and its value was 0.26 feet per day. A very questionable seepage velocity was calculated from this one hydraulic conductivity value and was found to be about 0.25 feet per day. The average of all tracer tests shown in Figures 30, 31, and 32 gave a tracer velocity of about 1.0 foot per day.

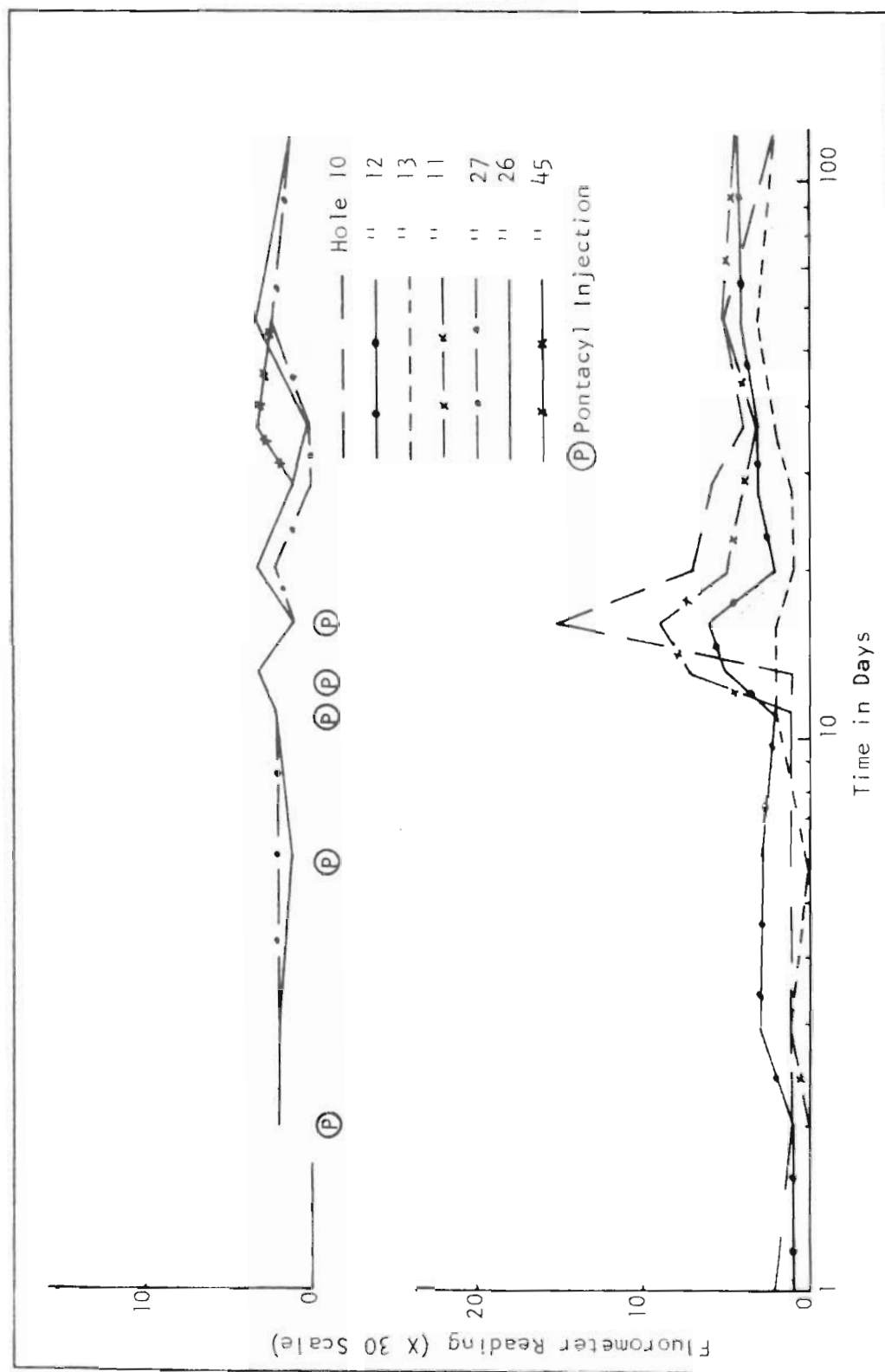


Figure 27. Relative dye concentrations at sample holes versus time since injection of dye (Clyde Site).

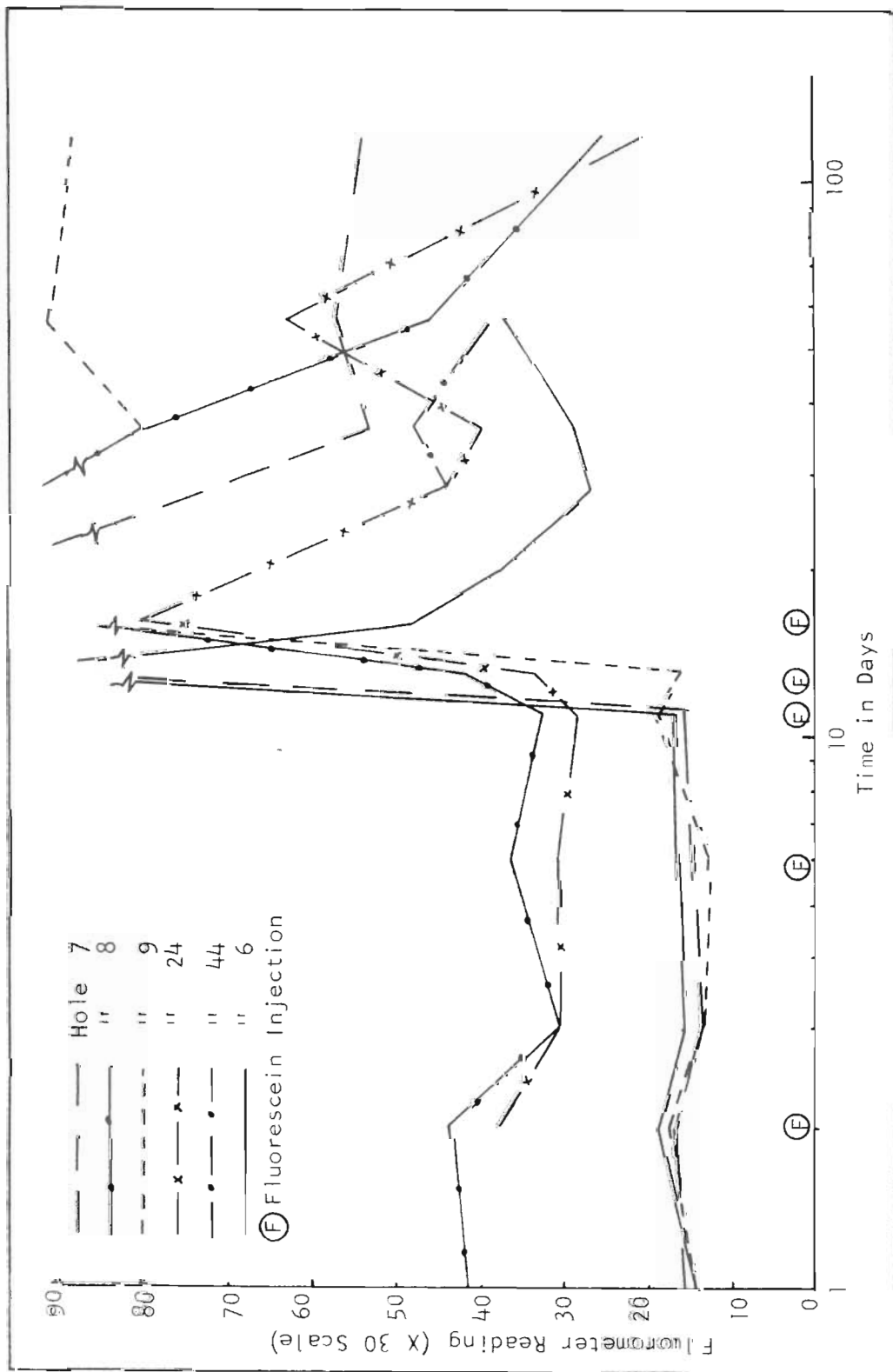


Figure 28. Relative dye concentrations at sample holes versus time since injection of dye (Clyde Site).



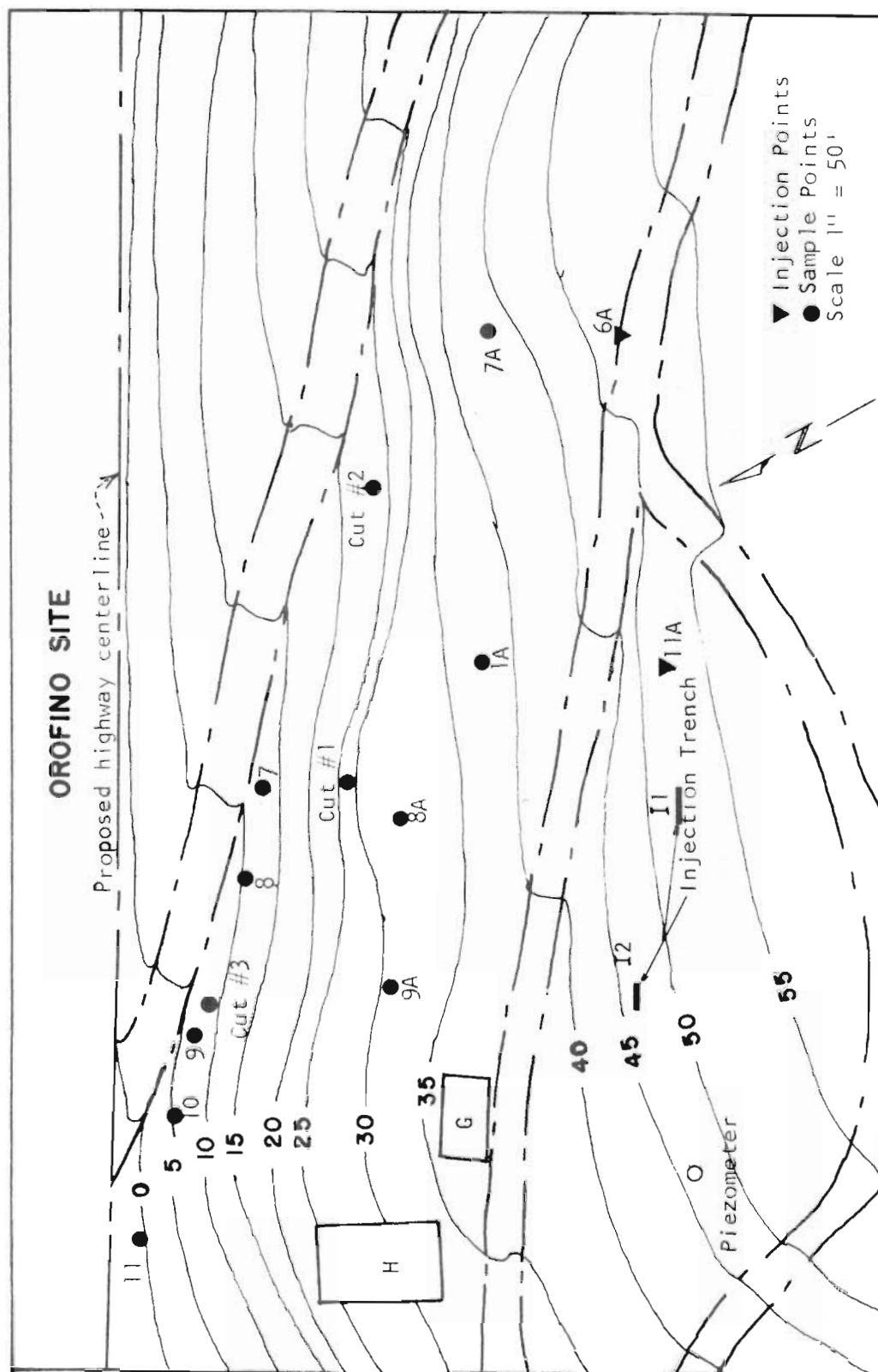


Figure 29. Map of Orofino Site.

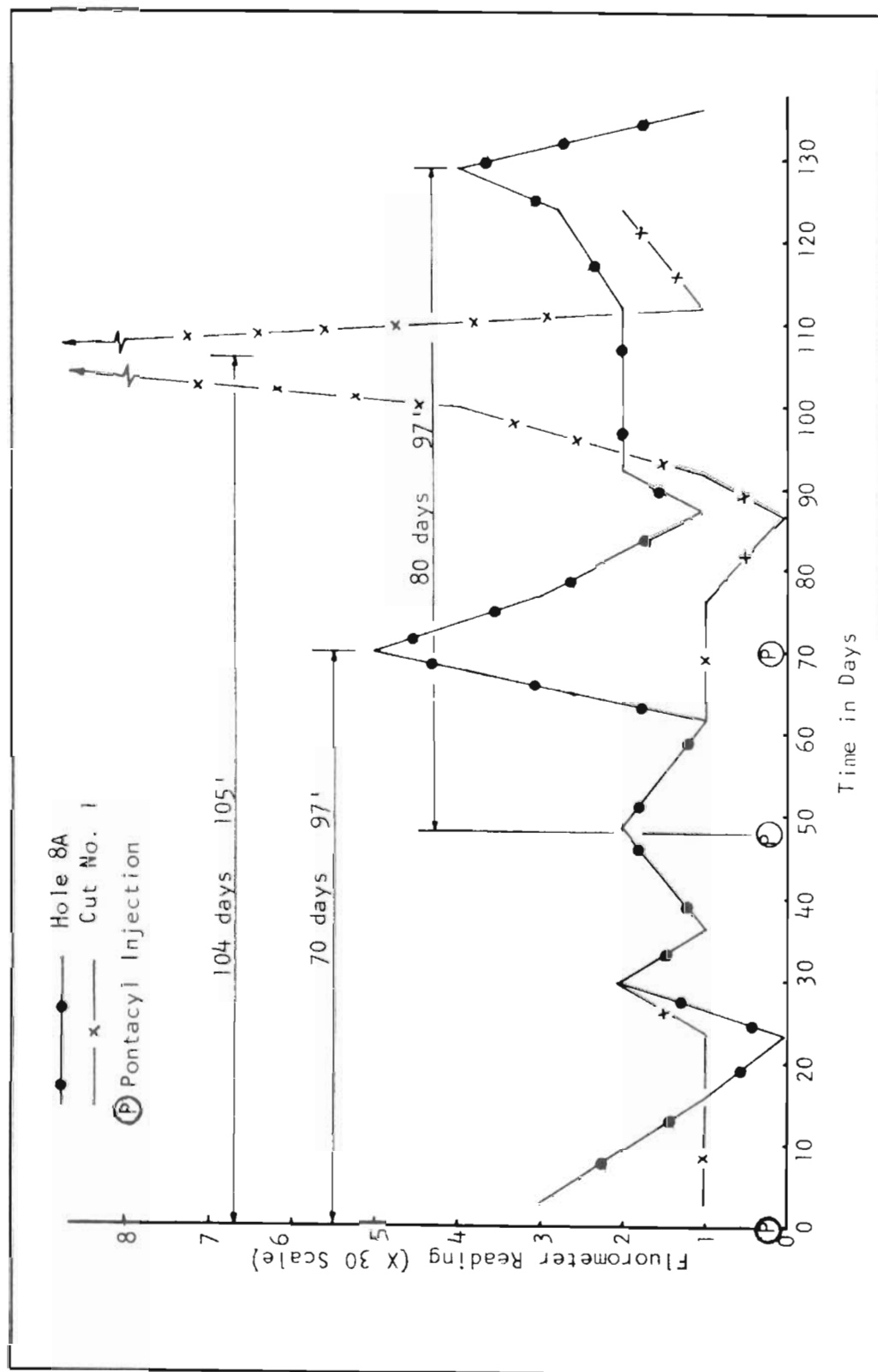


Figure 30. Relative dye concentrations at sample points versus time since injection of dye (Orofino Site).

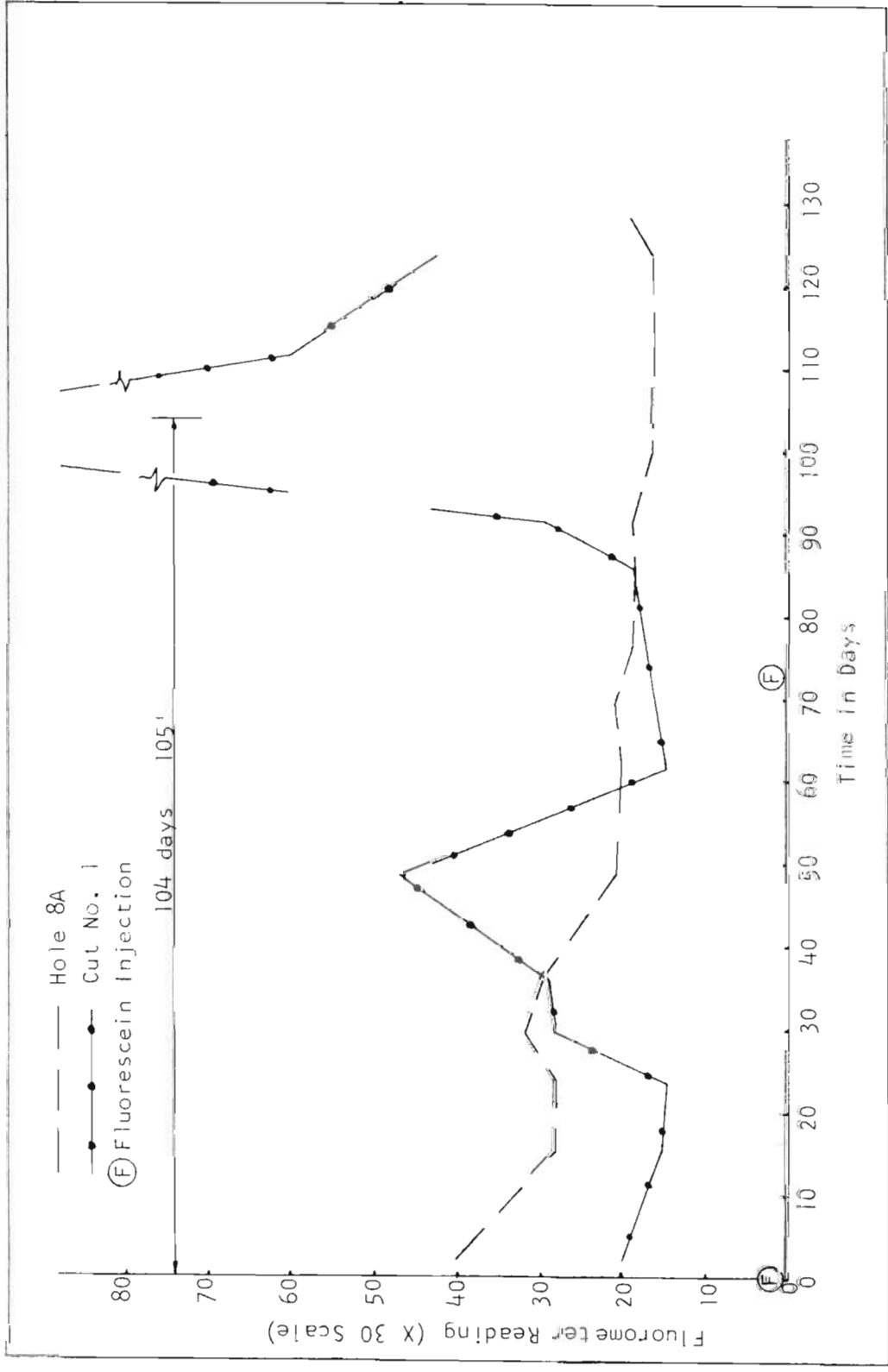


Figure 31. Relative dye concentrations at sample points versus time since injection of dye (Orofino Site).

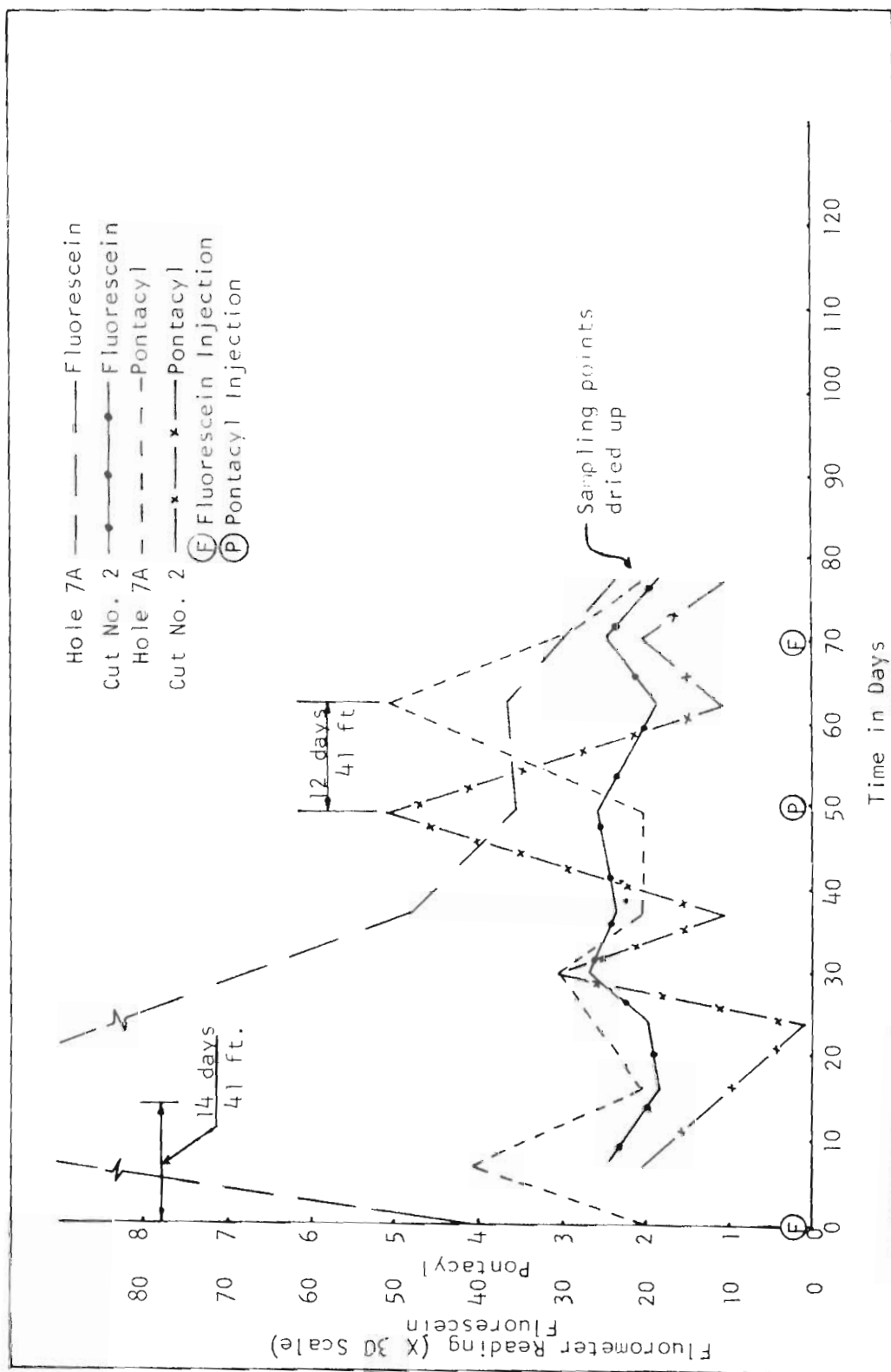


Figure 32. Relative dye concentrations at sample points versus time since injection of dye (Orofino Site).

### Kennedy Ford Site

A typical example of landslides, or more exactly mud flows, that are troublesome in the Palouse loess was located on Highway 95, 5 miles southwest of Potlatch in the SW1/4 sec. 17, T. 41 N., R. 5 W., on state highway right-of-way. This site was chosen for investigation because it had water seeping out of the cut slope into the roadside ditch almost continually. The site layout and typical soil information are presented in Figure 33.

The loess soil has a tendency for the flat soil particles to be oriented vertically rather than horizontally as is normally the case of most soils. Because of the vertical orientation, the hydraulic conductivity is generally greater vertically than horizontally. Therefore, during periods of heavy uniform rainfall the water can percolate down through the soil quite rapidly, but lateral movement is somewhat restricted. Impervious layers exist in the soil, which prevents further downward movement, and a perched water table tends to build up. As the water table builds up, pore water pressures increase and stability is reduced. Upon sufficient increase in pore water pressure, failure occurs, and the small, saturated, soil mass moves down into the ditch or even beyond the ditch onto the road. This description of loess soil failure is partly generally accepted as fact and partly conjecture. It is commonly accepted that the loess soils have greater vertical than horizontal hydraulic conductivities.

A limited attempt was made to substantiate the supposed loess soil failure. Two observation holes were drilled at selected points in the cut slope and on the flat above the backslope. Water-level readings were taken periodically from October 1964 to June 1965. These readings definitely showed a rapid rise of the water table during periods of prolonged rains and they also showed a less rapid drop of the water table during periods of no rain. Because the hole on the flat above the backslope was near the backslope, the gradient of the water table between the hole and the ditch was very steep which would account for the ground-water level dropping fairly fast. As the gradient decreased, the flow diminished, but did not entirely stop, even after prolonged periods of time.

A highly concentrated solution of pontacyl was injected in trenches I1 and I2, and in hole I3A. Rain water helped to take the dye into the soil-water system. Both visual and fluorometric detections were made of the dye at sampling points located on the cut slope. Pontacyl dye was visually detected in hole 3, hole 4, hole 5, and in two small seeps up the slope about 5 feet above holes 3 and 4 (Figure 34). The tracer moved about 45 feet, 1 foot vertical to 2 feet horizontal, in less than 15 days. Pontacyl was detected at holes 7 and 10 by fluorometric analyses within 45 days after the initial injection. The distance again was about 45 feet. The reason for the difference in time is believed to have been caused by the heavy rain that flooded injection trench I1, causing overland flow part of the way to the sampling points.

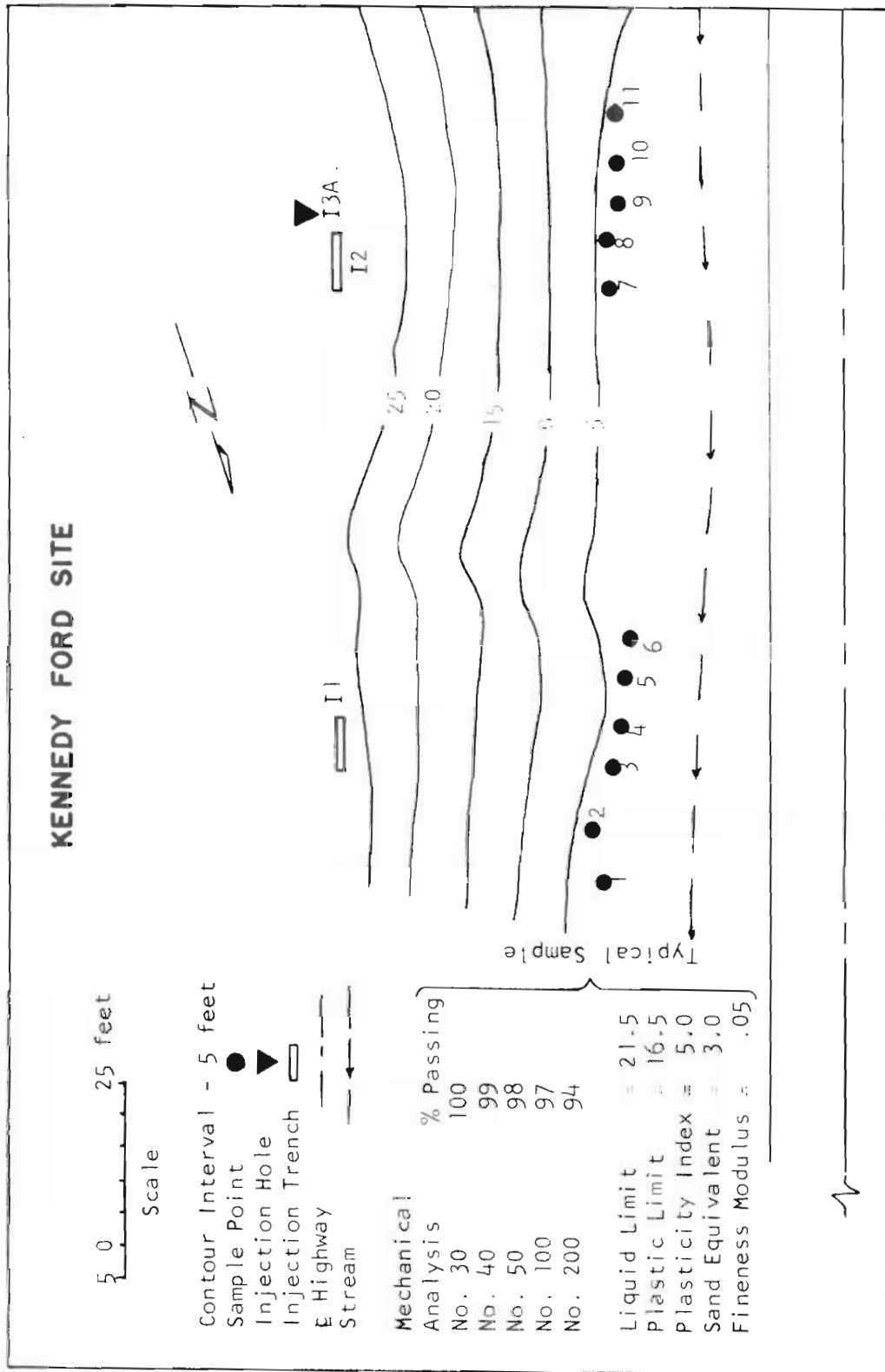


Figure 33. Map of Kennedy Ford Site.

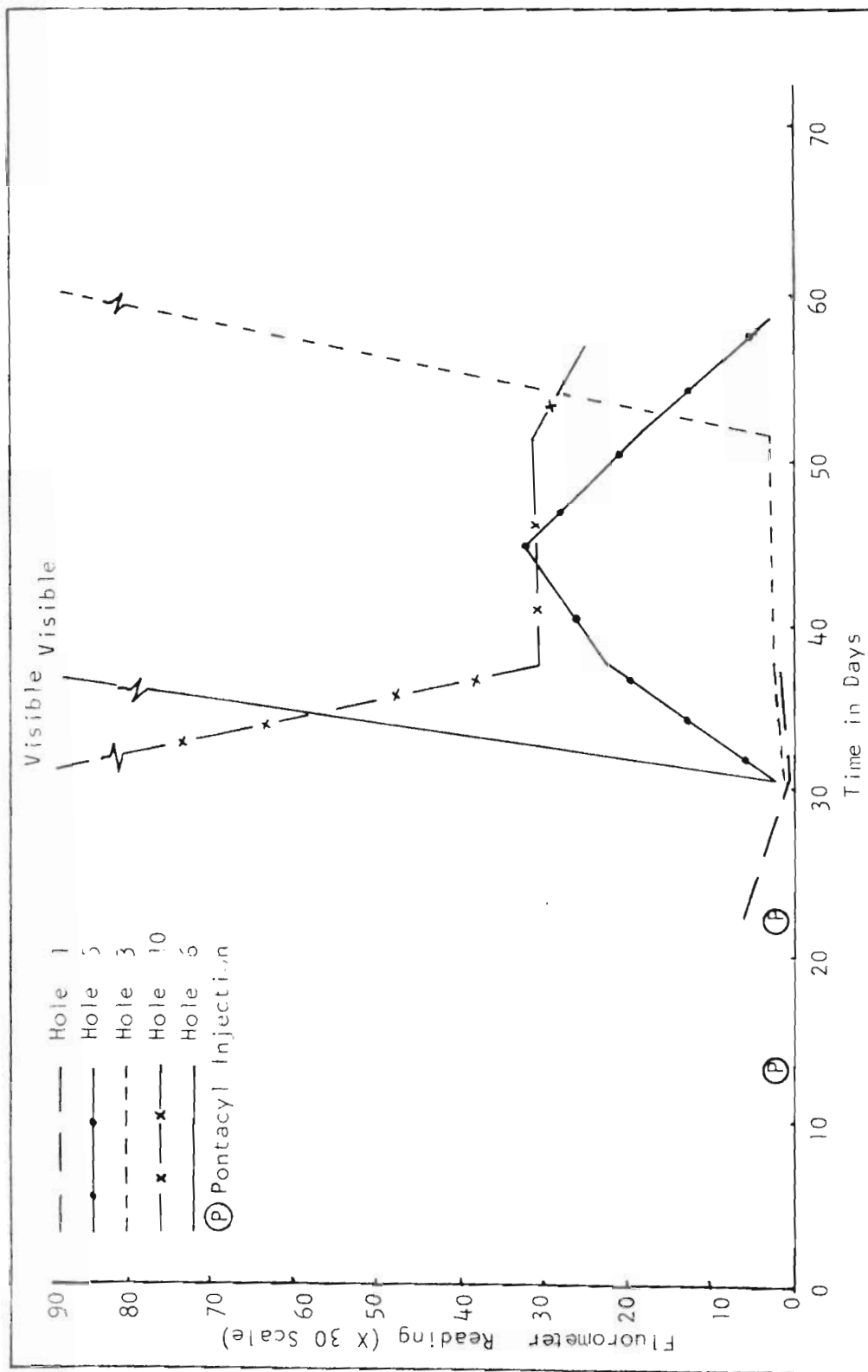


Figure 34. Relative dye concentrations at sample holes versus time since injection of dye (Kennedy Ford Site).

Auger-hole hydraulic conductivity tests were run at the site in the sampling holes. The tests gave values so low that procedural errors ruled out the possibility of calculating the hydraulic conductivity from these tests.

#### Brammer Site

An example of a large soil mass that becomes unstable as ground-water builds up is the Brammer slide. The Brammer Site is located about 1 mile southwest of Kendrick in the SE1/4 sec. 26, T. 38 N., R. 3 W., on state highway right-of-way. Each spring the mass begins to move, the scarp enlarges, and sluffing occurs. Maintenance costs to clean the "sluffed" material from the gutter or roadway could be reduced if the seepage water was intercepted before entering the area outlined by the scarp. Since the soil-rubble mantle is between 10 and 20 feet deep, interception of the water would be relatively easy if the direction from which the water enters the slide was known. This site appeared to be ideal for tracer tests because the many small seeps that emerged from the cut slope would serve as sampling points.

Injection holes were dug by the Department of Highways with a tractor-mounted back hoe. The location of the injection holes and sampling points are shown in Figure 35. The direction of water movement as determined by hydraulic gradient measurements is shown by an arrow. A typical soil profile and typical soil properties are also presented in the figure.

Pontacyl dye was injected in holes I1 and I2 on May 18, and May 20, 1965, at 150 grams per injection. Fluorescein dye was similarly injected in holes I3 and I4. Sampling was carried out at all points from May 18 to September 3, 1965, until the points dried up. No sampling was done in August due to lack of transportation. Hydraulic conductivity tests were not run in this area because of difficulty in drilling a hole to penetrate the water table.

Fluorometric readings of the samples were plotted and are presented in Figures 36, 37, 38, and 39. Both pontacyl and fluorescein were detected at several sampling points, from which an average velocity of about 2.3 feet per day was calculated. The maximum velocity was 4.3 feet per day and the minimum velocity was 1.1 feet per day. Of course, part of the variation was due to some of the sampling points not lying along the same flow path as that of the injection hole. Therefore the dye movement to these holes was due partly to dispersion. Concentration peaks shown on the figures for this site definitely show tracer arrival at the sampling points.

#### Ahsahka Sites

New landslides develop or old landslides are reactivated almost every spring along sections of the Ahsahka grade. A typical slide and the method of cleanup is shown in Figure 40. Much of the Ahsahka grade is cut through an area of many old small landslides as evidenced by the surrounding terrain. Landslides develop in the backslopes and also in



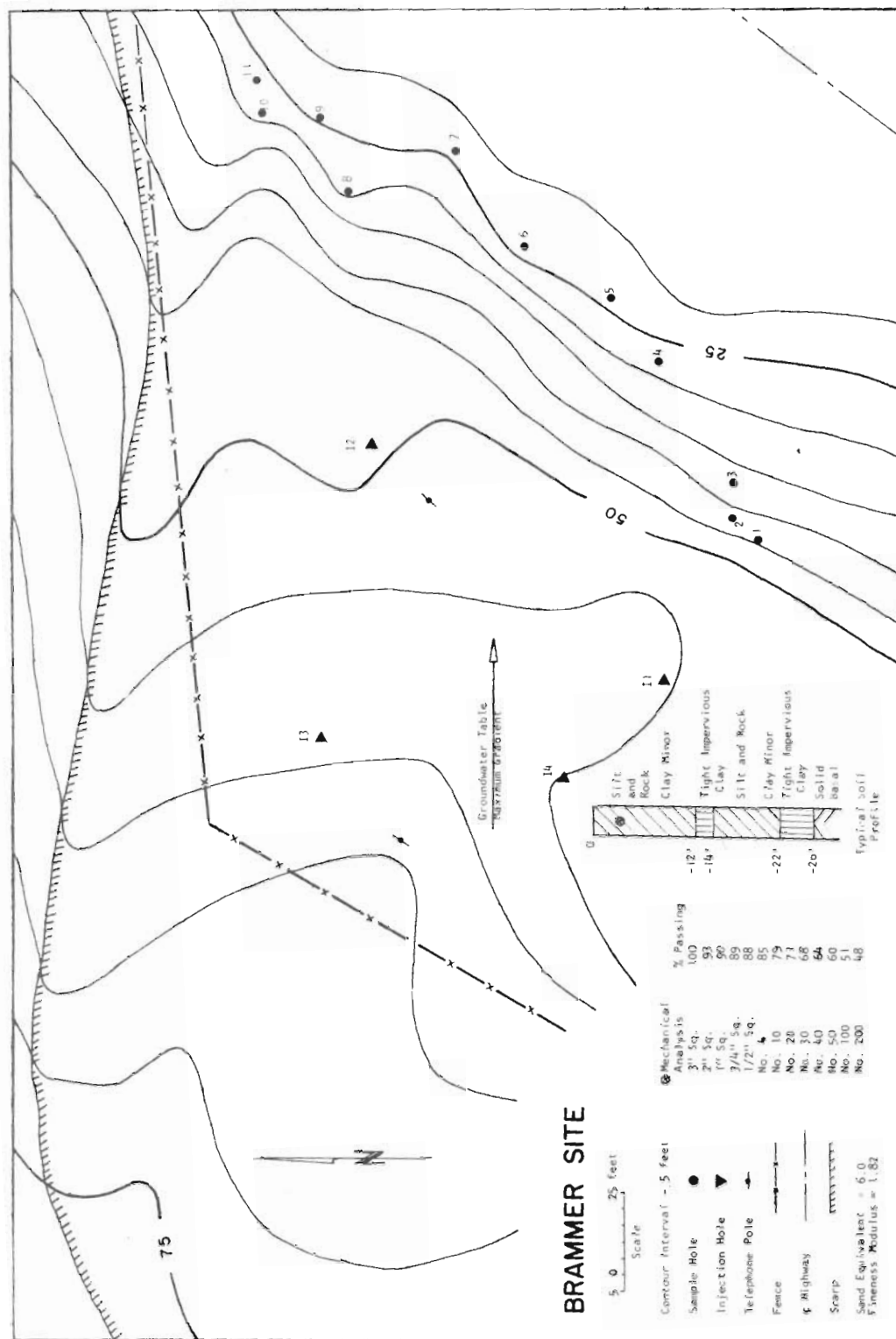


FIGURE 35. MAP OF BRAMMER SITE.

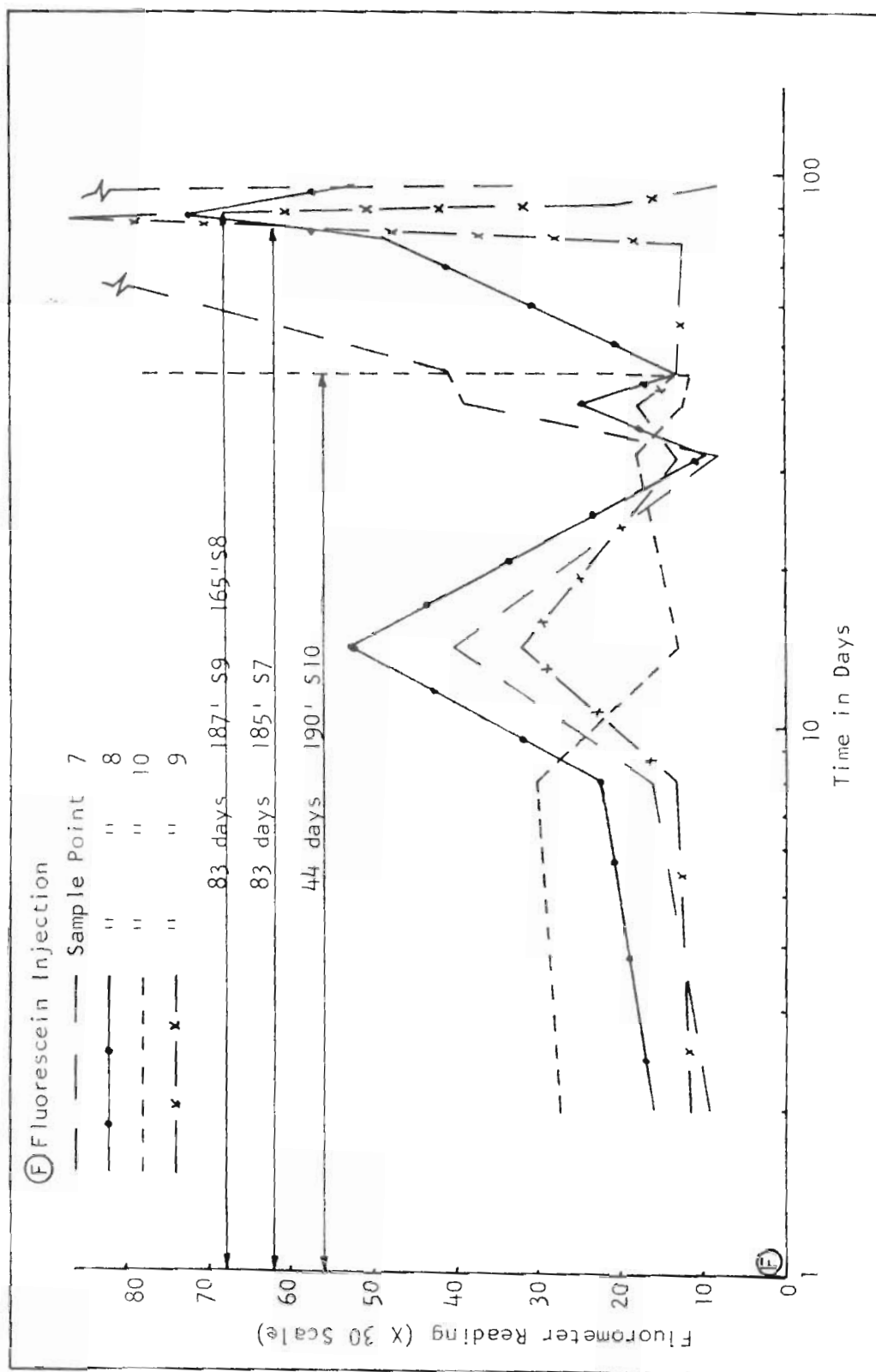


Figure 36. Relative dye concentrations at sample points versus time since injection of dye (Brammer Site).

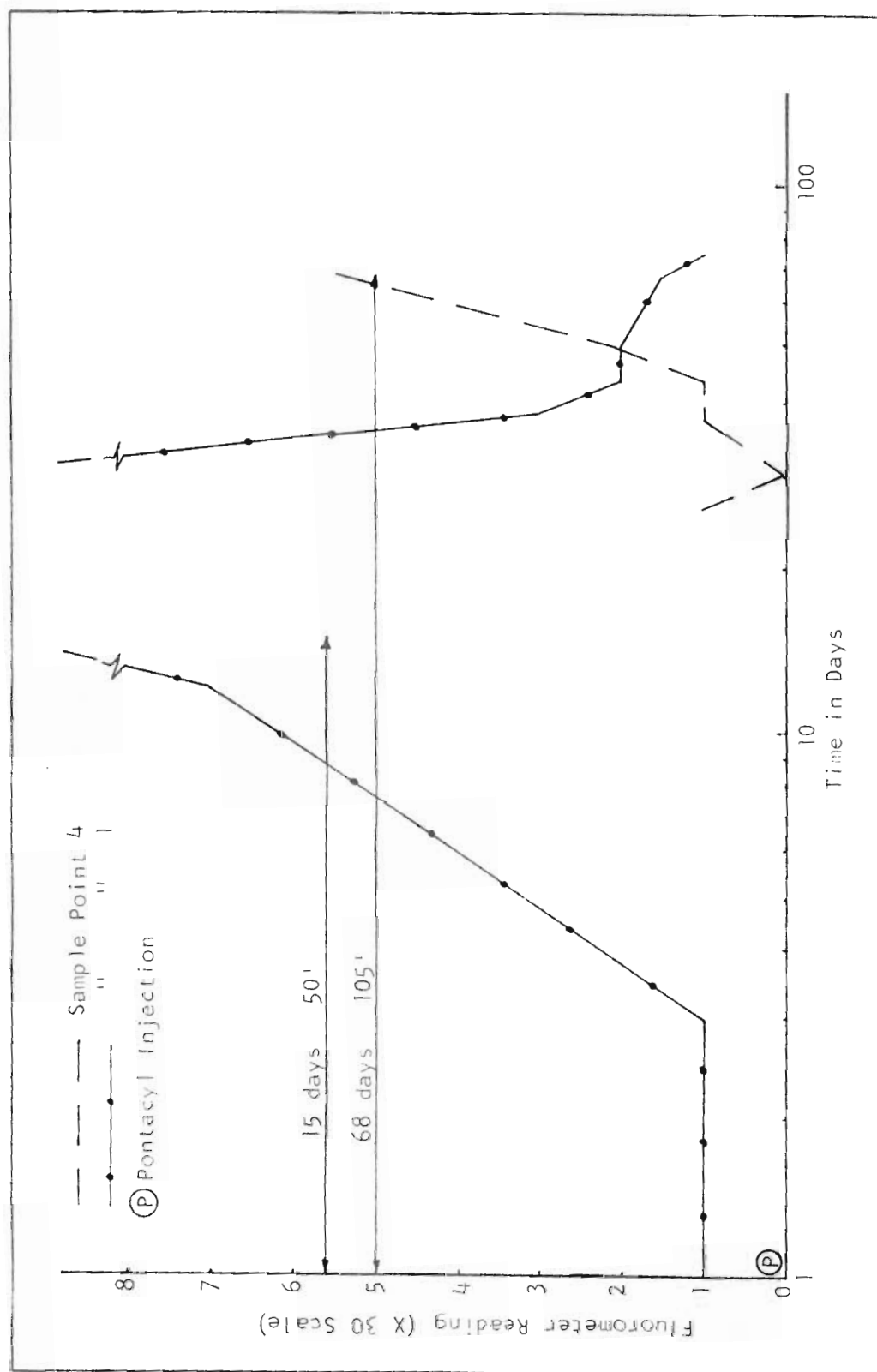


Figure 37. Relative dye concentrations at sample points versus time since injection of dye (Brammer Site).

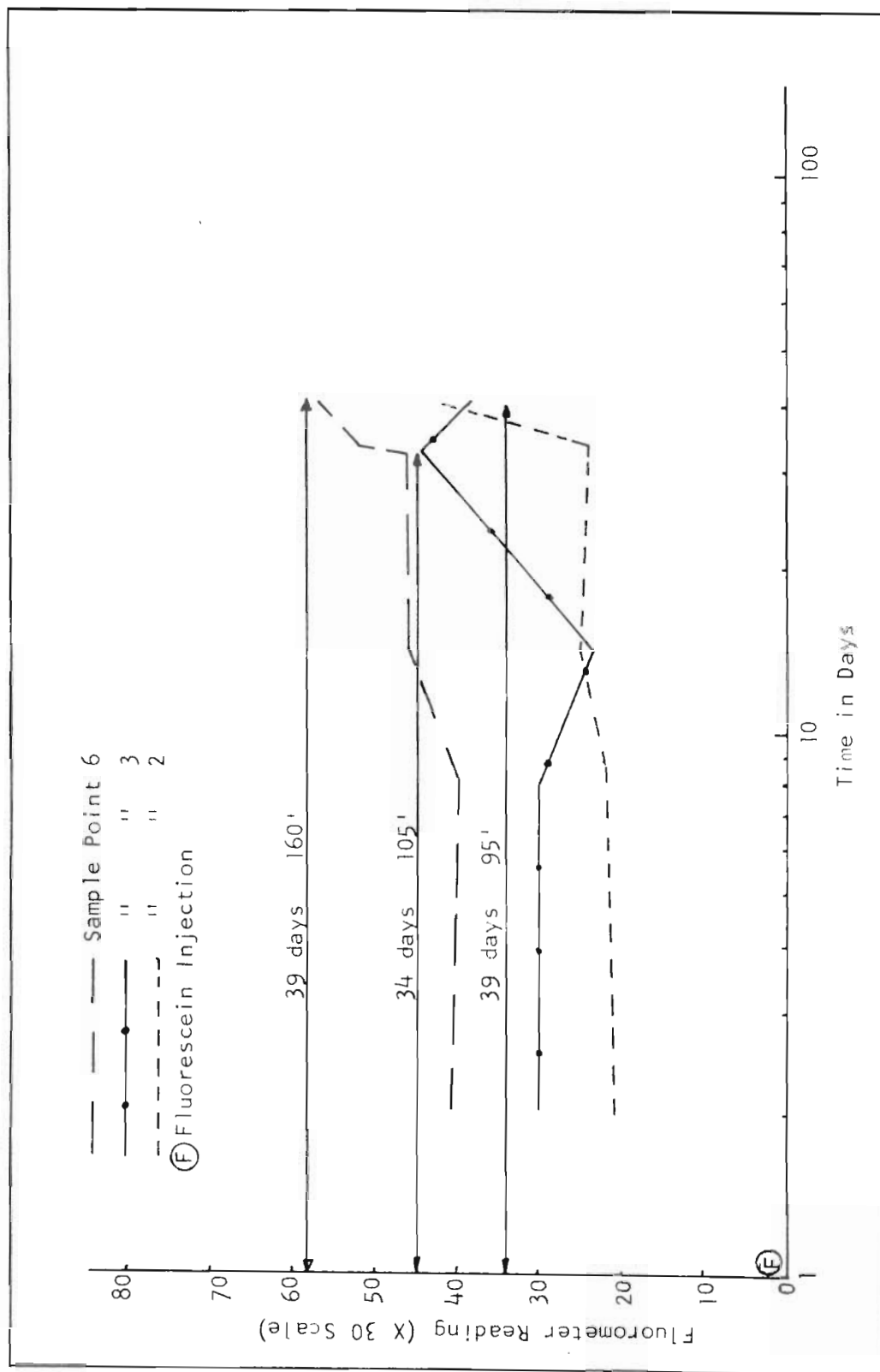


Figure 38. Relative dye concentrations at sample points versus time since injection of dye (Brammer Site).

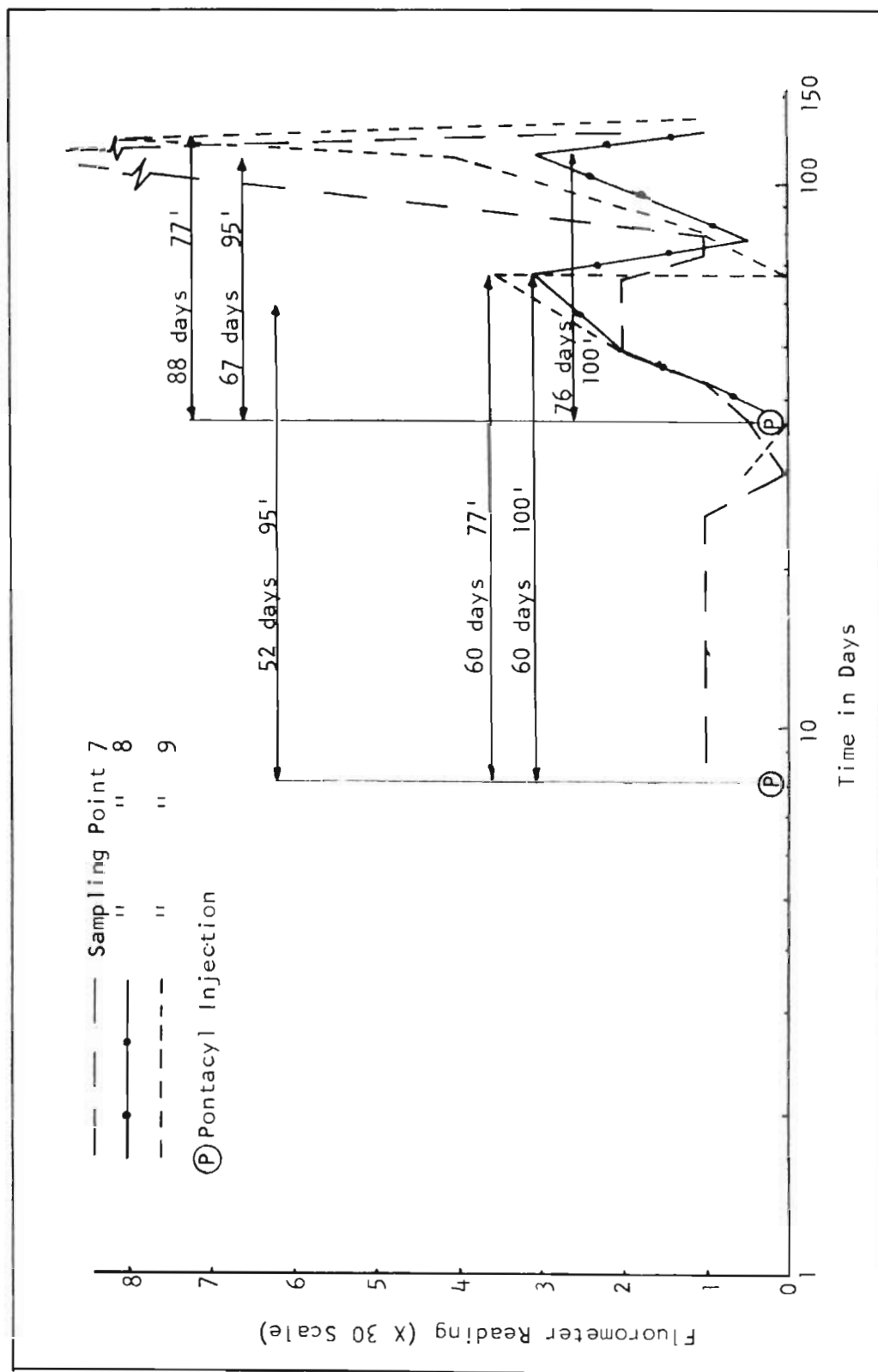


Figure 39. Relative dye concentrations at sample points versus time since injection of dye (Brammer Site).



Figure 40. Typical slide and method of maintenance.  
(Ahsahka Grade)

many of the fills. It was obvious that groundwater was a great contributor to the instability and movement of the soil masses because the movement was confined primarily to the spring months of abundant rainfall. During the wet spring months, the water table rises nearly to the ground surface but as the dryer months come the water table drops to several feet below the ground surface. Three small areas, not more than 1/2 mile apart, were chosen for tracer studies and were designated as the Hall, Pole, and Sutton Sites. The Hall and Pole Sites were located 2 1/2 miles west of Ahsahka in the SW1/4 sec. 32, T. 37 N., R. 1 E., on state highway right-of-way. The Sutton Site was located 2 miles west of Ahsahka in the NE1/4 of sec. 32 also on state highway right-of-way.

The underlying soil was a rubble, silty-clay mixture. It was impossible to drill holes into the soil with the two-man power auger or with a hand auger because of the interspersed rubble. Injection holes or pits deep enough to encounter the groundwater table were hand-dug at various locations in the backslope slide areas. No holes were necessary for sampling points because samples were taken along the cut slope and the ditchline where seepage emerged. Samples were collected weekly from the time of injection until seepage discontinued at the sampling points.

Fluorescein and pontacyl dyes were injected into the injection holes by placing 50 to 100 grams into the holes either in concentrated form or in solution. Most of the injections were made on April 20, 1965, although later injections were made at some points.

In conjunction with the tracer tests, the quantity of water that emerged as seepage was measured at various times. This was done by collecting the flow for a given time interval and then measuring the flow quantity.

Tracer tests at the sites along Ahsahka grade yielded results that were difficult to interpret. The most important reason for this was that the dye used as fluorescein dye at these sites was not fluorescein, because of a mistake in shipment from the supplier. However, the material possessed fluorescent properties that could be measured with either the fluorescein or pontacyl filter arrangement in the fluorometer. Another reason that interpretation of the tracer results was difficult was that the injection holes were too close to each other in many cases, which further complicated the effect of using the wrong dye.

Even though these problems occurred, some definite results can be pointed out. Figure 41 shows that at the Hall Site, dye X (the dye used as fluorescein) was carried by the seepage water from the injection point to sampling point 1, about 20 feet in 7 days. A similar pattern developed after the second injection of dye X. The third injection did not affect readings at sampling point 1 because it was made at a different point.

Figure 42 shows that a very similar pattern was made by pontacyl readings on samples from sampling point 1. This was caused by dye X giving both pontacyl and fluorescein readings. A dirty sample gave high readings, but these readings were not attributed to the presence of a dye. Some of the other high fluorometric readings at other sampling

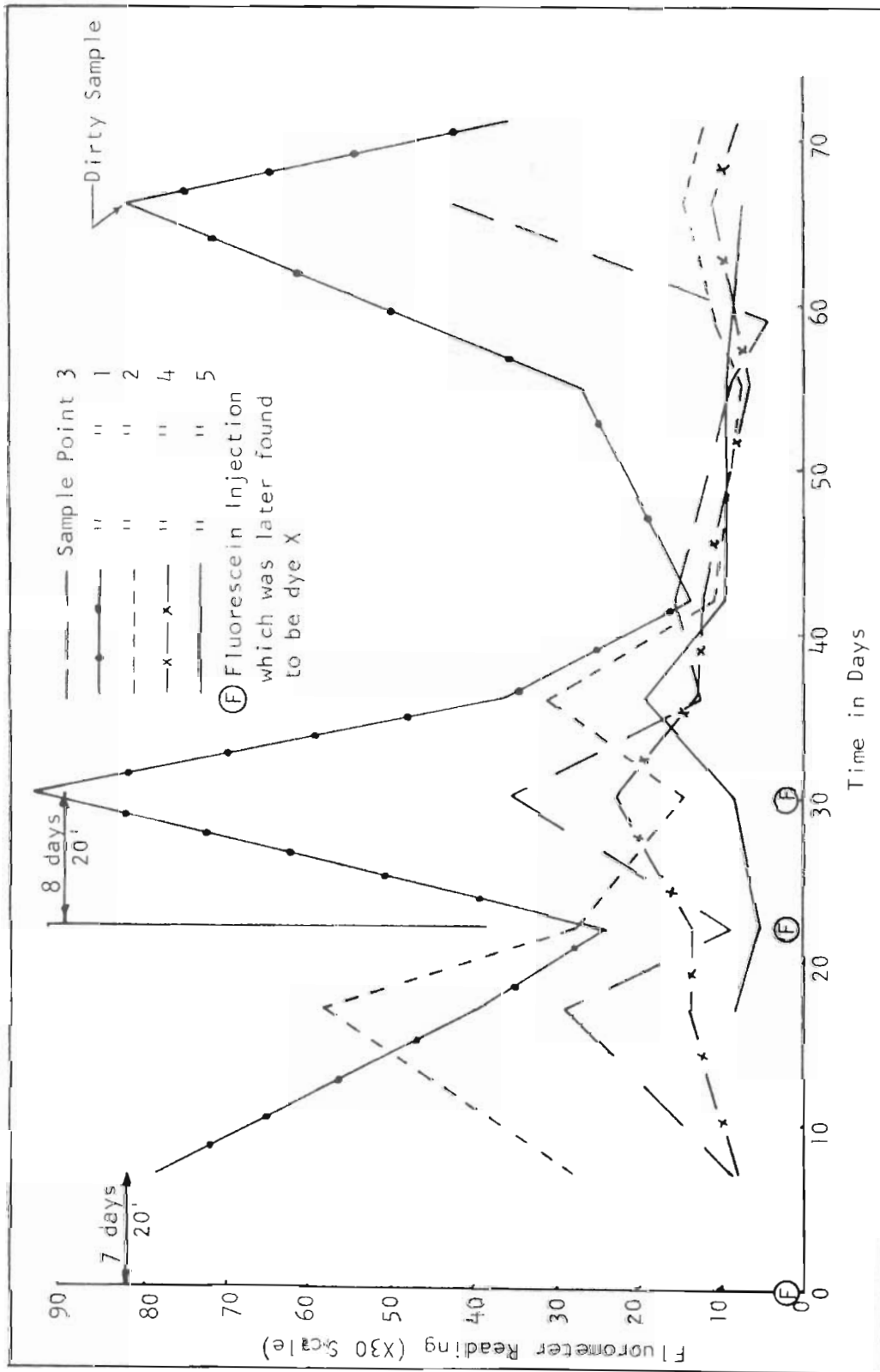


Figure 41. Relative dye concentrations at sample points versus time since injection of dye (Ahsahka - H211 Site).



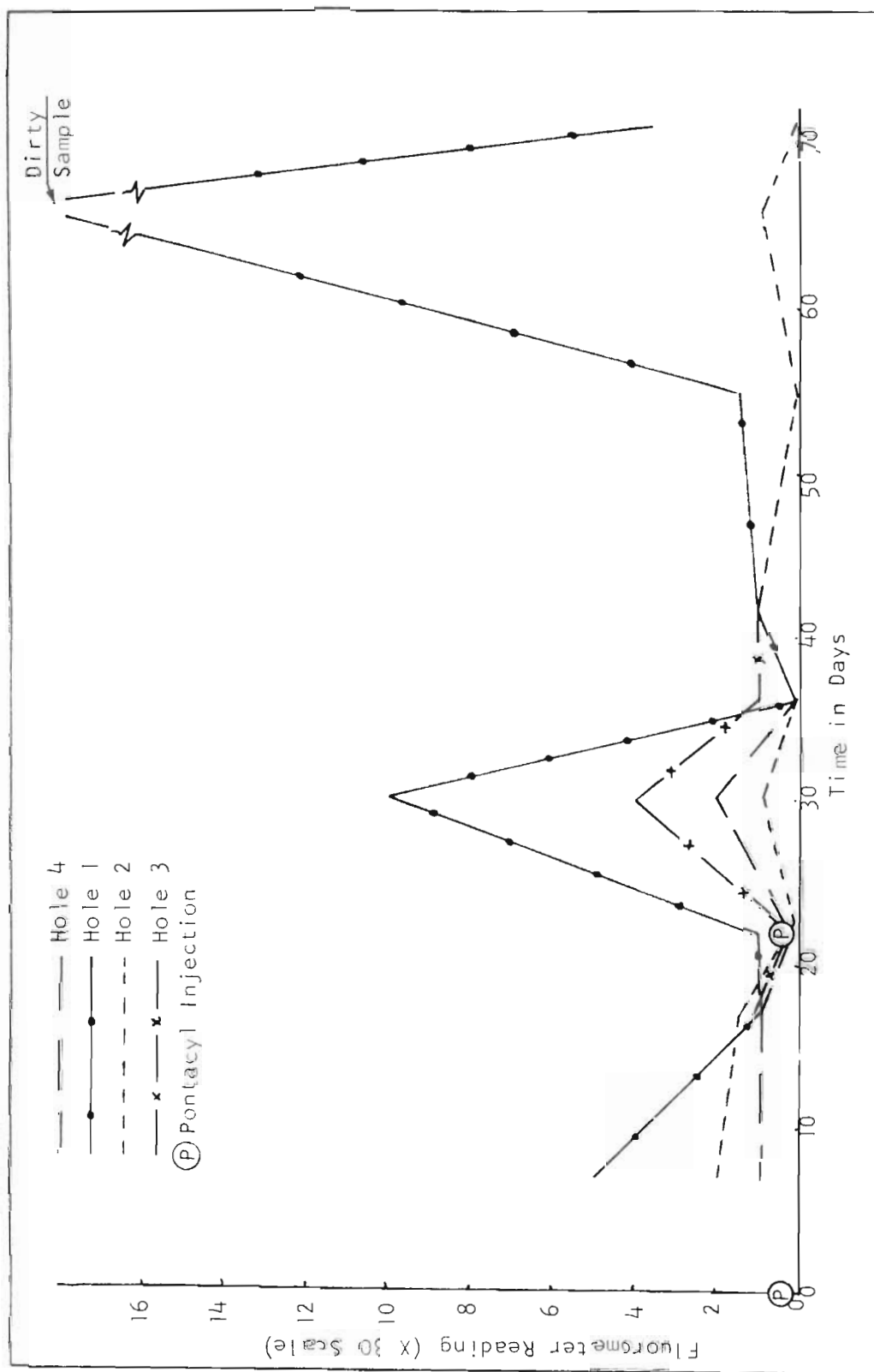


Figure 42. Relative dye concentrations at sample points versus time since injection of dye (Ahsahke - Hall Site).

points in the Hall Site are undoubtedly due to the presence of dye moving with water from injection points to the sampling points, but no definite patterns can be seen.

The Pole and Sutton Sites both yielded the same pattern of results as can be seen in Figures 43 and 44. Passage of the dye through the soil definitely occurred and the approximate velocity of the groundwater was 1.5 feet per day. This movement was effectuated by a hydraulic gradient of about 1 foot in 4 feet that existed during the testing period.

The quantity of seepage water emerging from the cut slope and ditchline continually decreased at all Ah-sahka sites, except when heavy rains fell to recharge the areas. Sharper fluctuations in the flow rate occurred at the Pole and Sutton Sites than at the Hall Site. This was attributed to the Hall Site being supplied with seepage water from a small pond lying just above the site, and outside of the Highway Department's right-of-way.

#### Huff Site

A known year-round groundwater flow that emerged on the face of a cut slope existed at the Huff Site. Since the quantity of flow from the area was substantial, this site was selected for field tracer tests. The Huff Site was located 4 miles west of Priest River in the SW1/4 sec. 20, T. 56 N., R. 5 W., on the north side of U. S. Highway 2. The general layout, including injection and sampling points, and also the log and characteristics of the soil are shown in Figure 45.

Holes were drilled with both the two-man auger and the Department of Highway's mobile, truck-mounted drill rig. Casing was required to maintain open holes; otherwise, the fine saturated sand would immediately fill the holes. The holes were drilled up-gradient from the sampling points so that injected tracers could move with the groundwater toward the sampling points.

The main water-bearing layer was composed of a clean sand which laid directly above and in contact with an impervious layer of silty clay. The general slope of the impervious layer was estimated from the drilling logs to be about the same as the slope of the undisturbed ground, which was about 1 foot in 9 feet.

Injections of both fluorescein and pontacyl were made to determine the groundwater movement and to make a comparison to determine which dye was the most effective as a tracer for use in this particular soil. Hydraulic conductivity tests were run in the cased holes in hopes of correlating groundwater velocities determined from hydraulic conductivity and groundwater slope with groundwater velocities determined by tracers. Flow quantities and water-table readings were taken periodically.

Typical results of the tracer tests are shown in Figures 46 and 47. By inspection of these figures, it appears that the time interval between samplings may have been too long which accounts for not detecting the arrival of the dye from the first injection. Detection of dyes from the

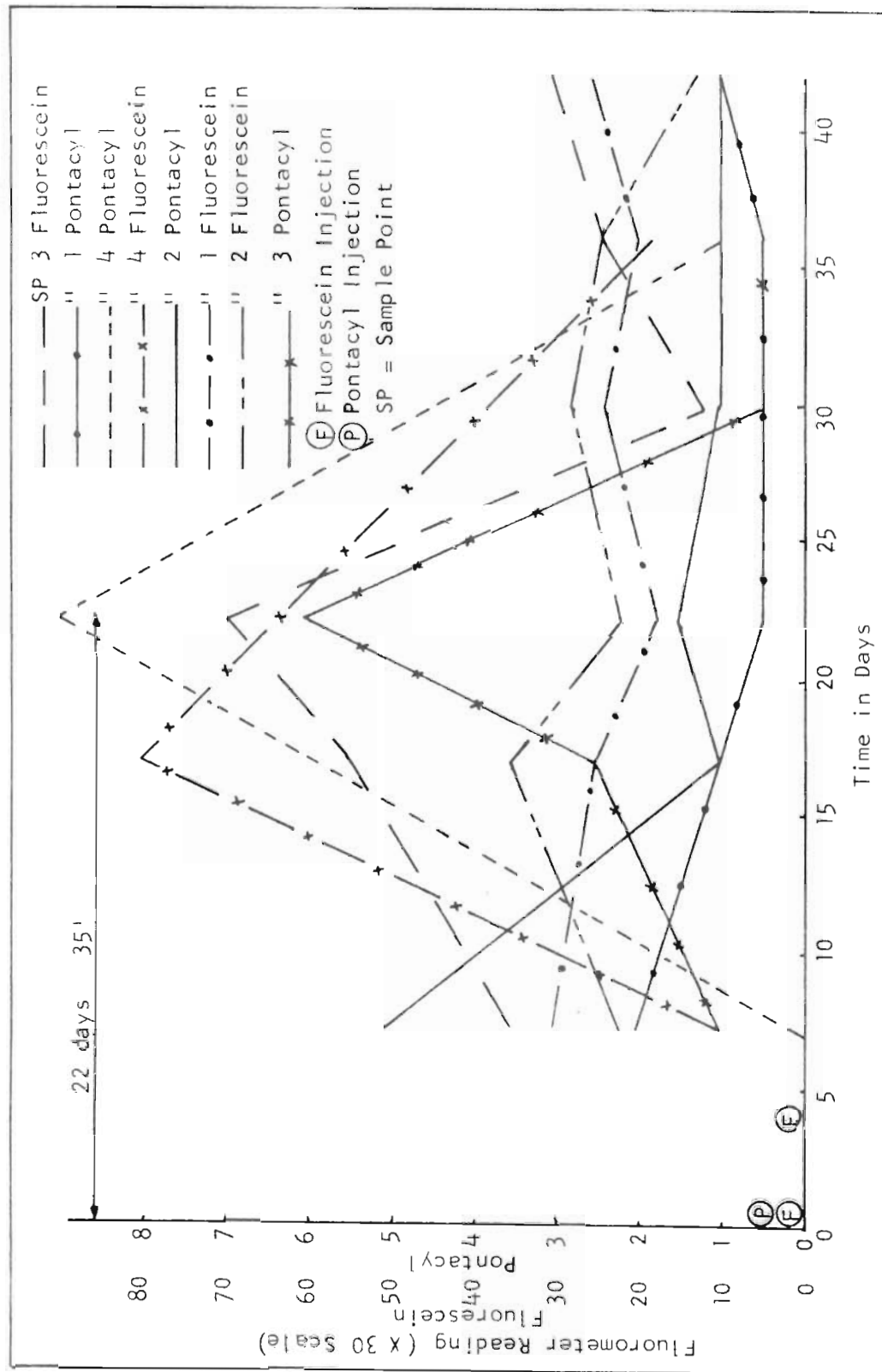


Figure 43. Relative dye concentrations at sample points versus time since injection of dye (Ahsahka - Pole Site).

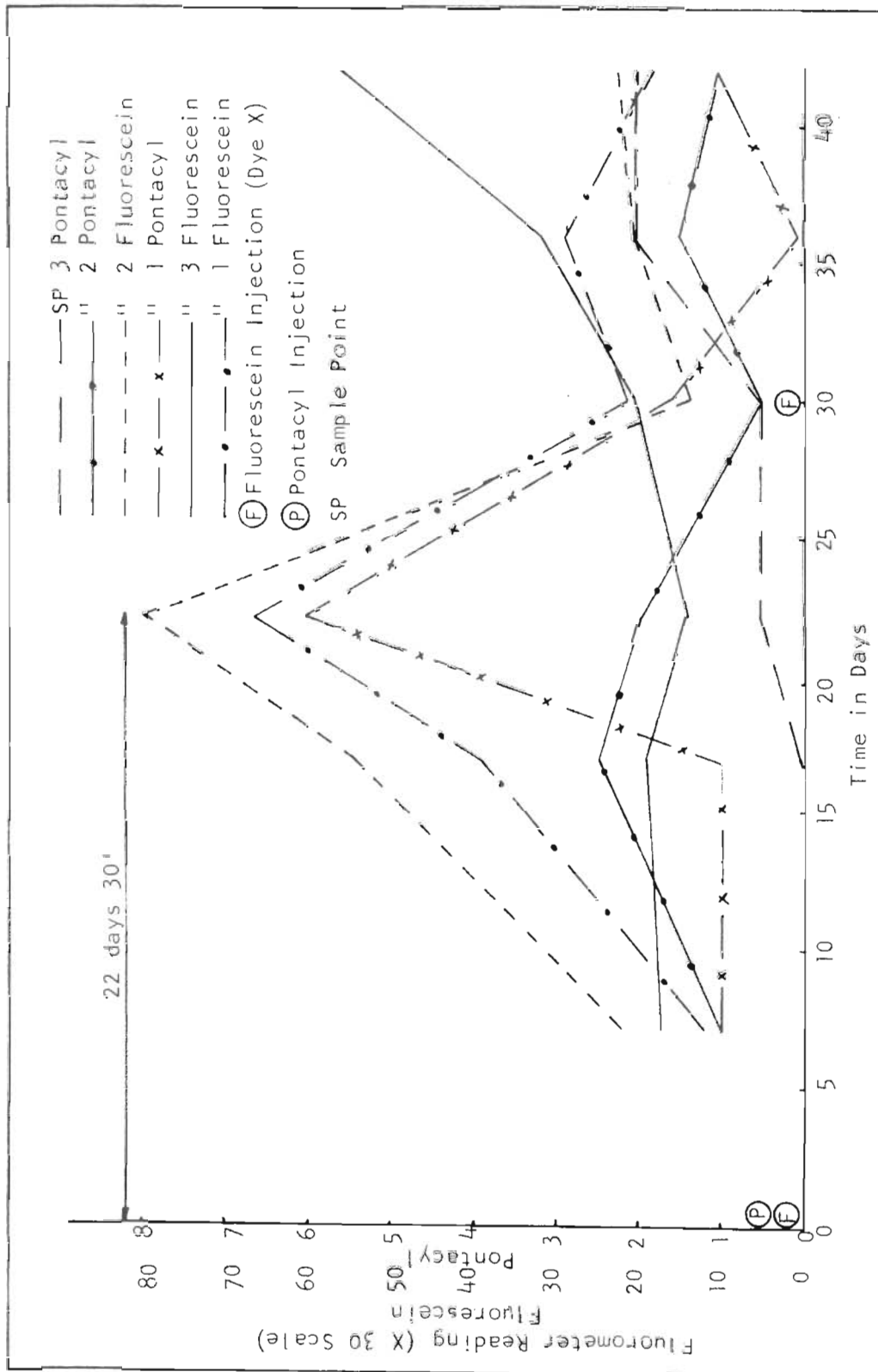


Figure 44. Relative dye concentrations at sample points versus time since injection of dye (Ahsahk - Sutton Site).

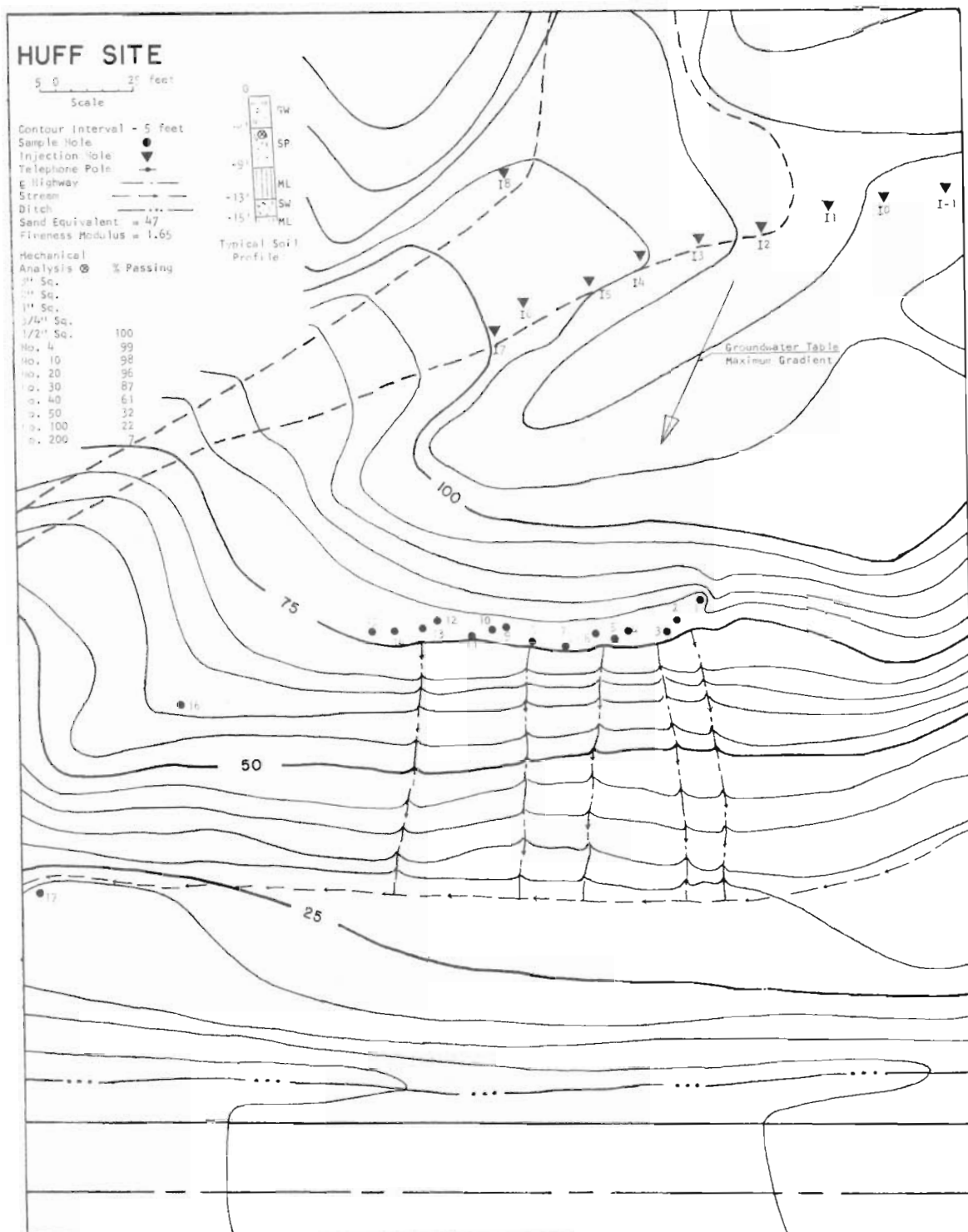


FIGURE 45. MAP OF HUFF SITE.

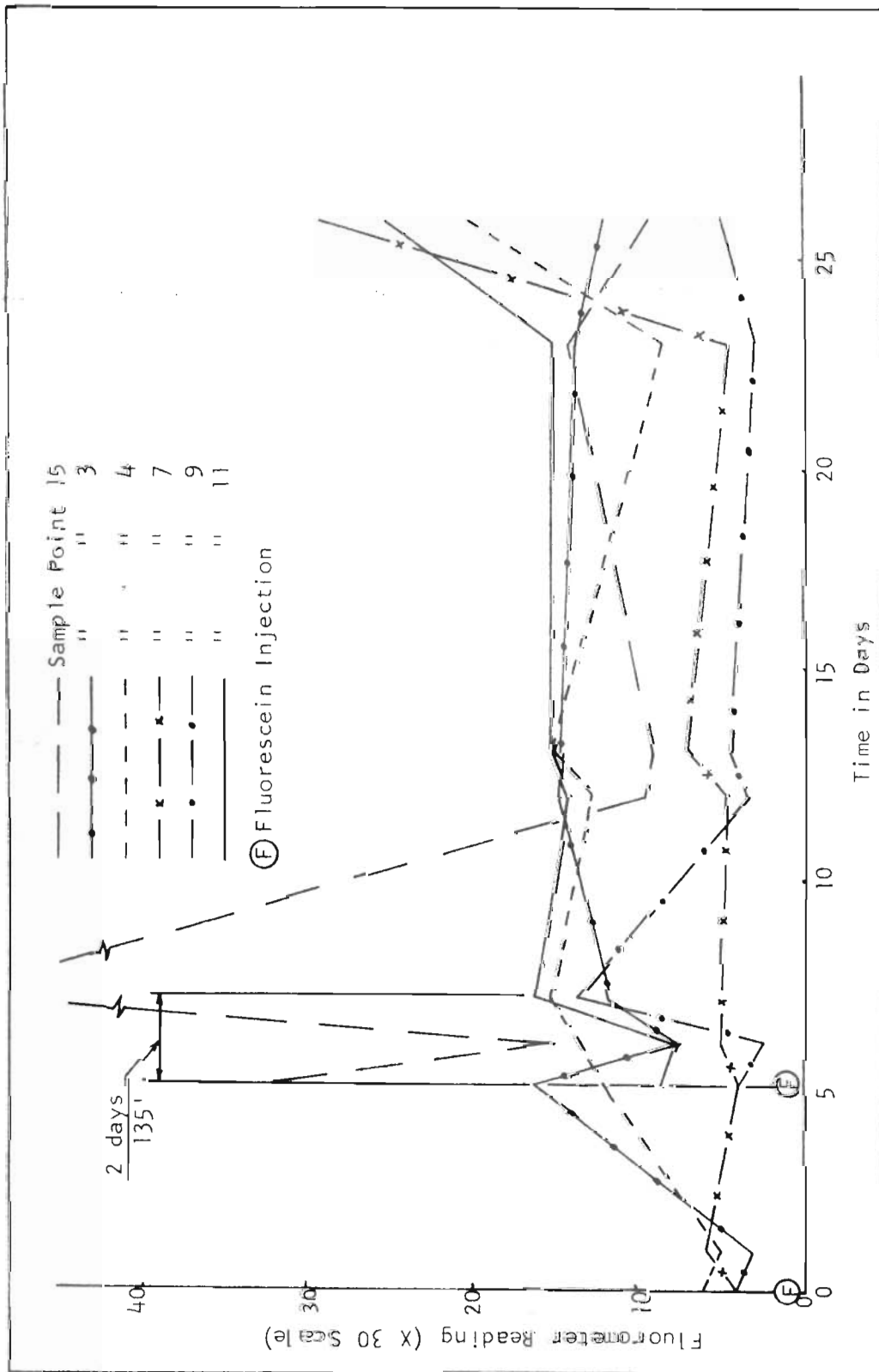


Figure 46. Relative dye concentrations at sample points versus time since injection of dye (Huff Site).

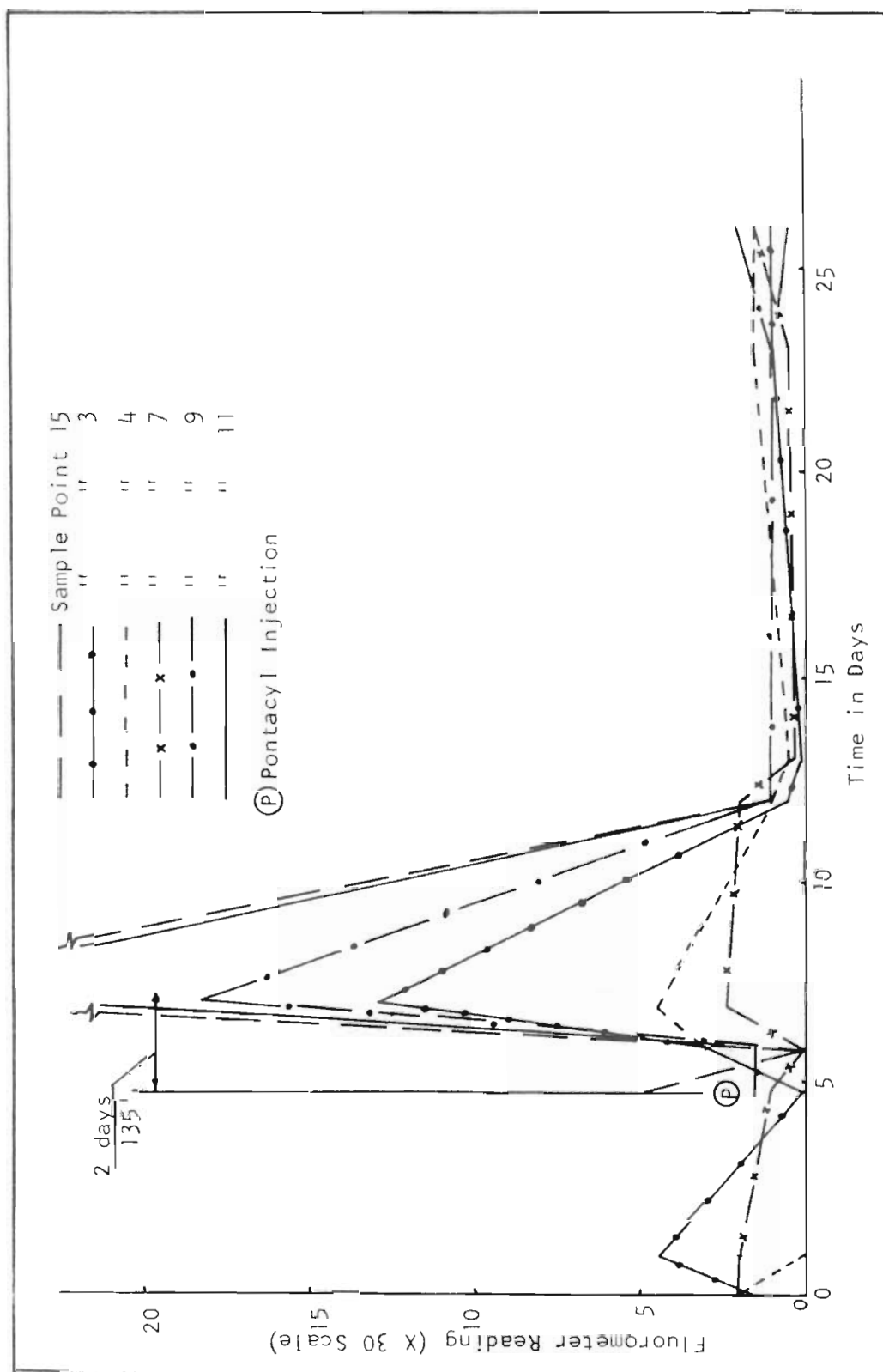


Figure 47. Relative dye concentrations at sample points versus time since injection of dye (Huff Site).

second injection was made at many sampling points two days after the injection. Since the average distance from injection to sampling points was about 135 feet, the velocity was approximately 70 feet per day.

The data collected from hydraulic conductivity tests fluctuated over wide ranges. Generally the results of the hydraulic conductivity tests showed much lower values than anticipated. Superficial velocities computed from hydraulic conductivity and the groundwater-table slope ranged from about 5 feet per day to less than 0.1 foot per day.

The quantity of flow was measured at a collector ditch below the sampling points. Fluctuations of flow occurred due to transpiration and evaporation of the water from the slope before it reached the measuring point, but the initial quantity of seepage flow emerging on the cut slope did not appear to change much throughout the testing period.

#### Robinson Site

The Robinson Site offered an opportunity to trace a known groundwater flow. The site was located 1 mile west of Priest River in the SE1/4 sec. 22, T. 56 N., R. 5 W., on the north side of U. S. Highway 2. Figure 48 shows the area, a typical log, soil characteristics, and the hole patterns chosen for tracer studies. The pond shown usually had water in it throughout the year which meant that water was always available to seep from the pond to the perforated drain buried under the highway ditch. The soil underlying the site was mostly silt with a fairly impervious layer of blue silty clay about 3 to 6 feet below the bottom of the highway ditch.

Four injection holes were drilled with the two-man power auger along the south side of the pond. Concentrated solutions of pontacyl, fluorescein, and FD&C Red #2 were separately injected into these cased holes in 1/2 gallon slugs.

Fifteen sample holes were drilled just north of the perforated drain, all of which required casing to keep the holes open. Other holes were drilled with the Department of Highway's truck-mounted drill. Six of these were located on a line about 40 feet south of the injection holes. These holes were drilled and cased to be used as subsequent sampling points. One drill hole, DH1, was drilled 20 feet deep from which a log was made.

Hydraulic conductivity tests were run in the cased holes to see if some correlation could be made between the velocity computed by hydraulic conductivity and water-table gradient and the velocity determined by tracer tests. Water-level readings and quantity of flow measurements were taken in an attempt to make further correlations.

The results of the tracer tests were highly irregular and impossible to interpret. Figure 49 shows readings for pontacyl at several of the sampling points. At first look it appears that pontacyl was detected at most of the sampling points about 55 days after injection. But upon close examination, DH3 and DH6, which were both only about 40 feet from the injection point and should have shown earlier and higher readings than the sampling points, did not show a substantial amount of pontacyl.



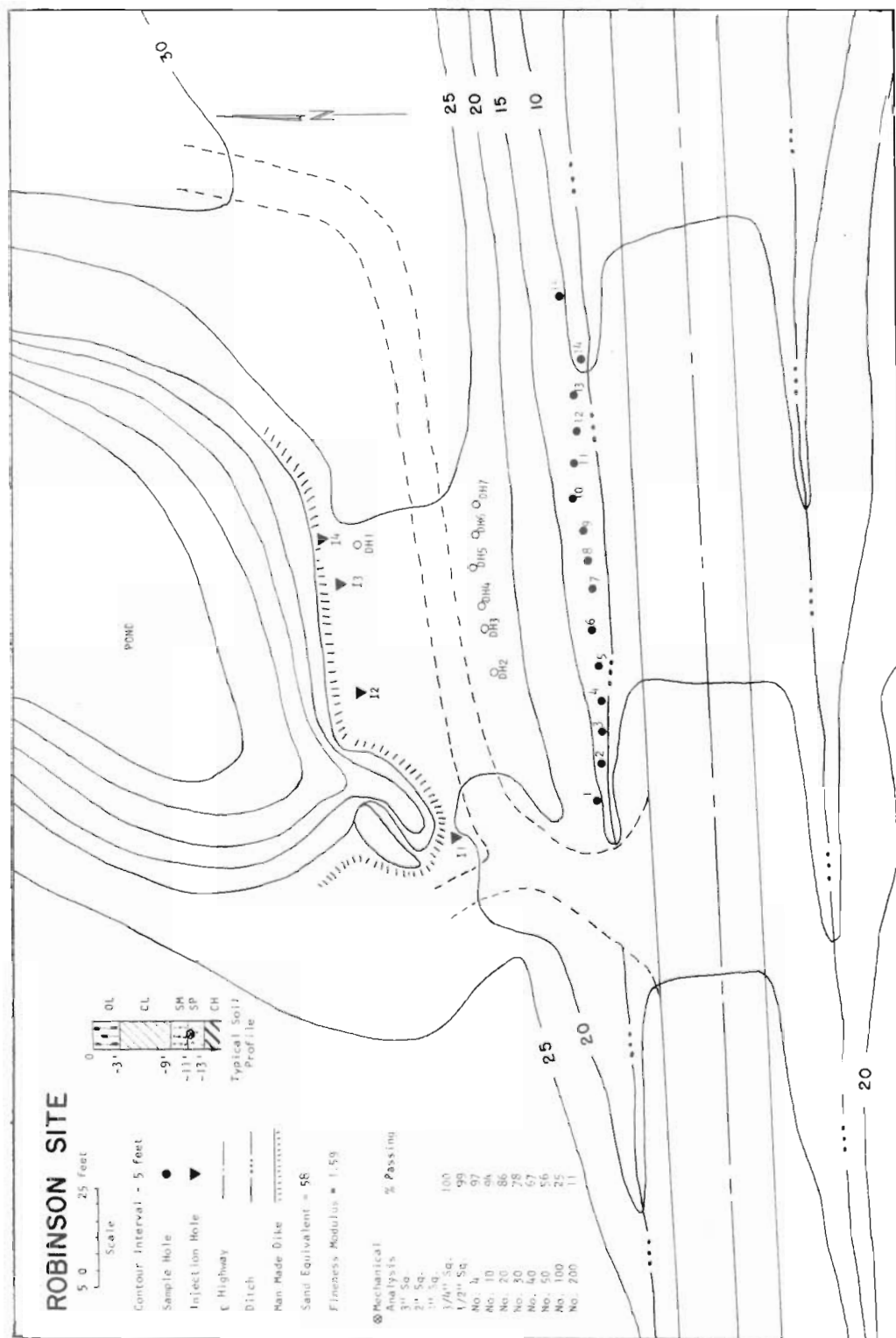


FIGURE 48. MAP OF ROBINSON SITE.

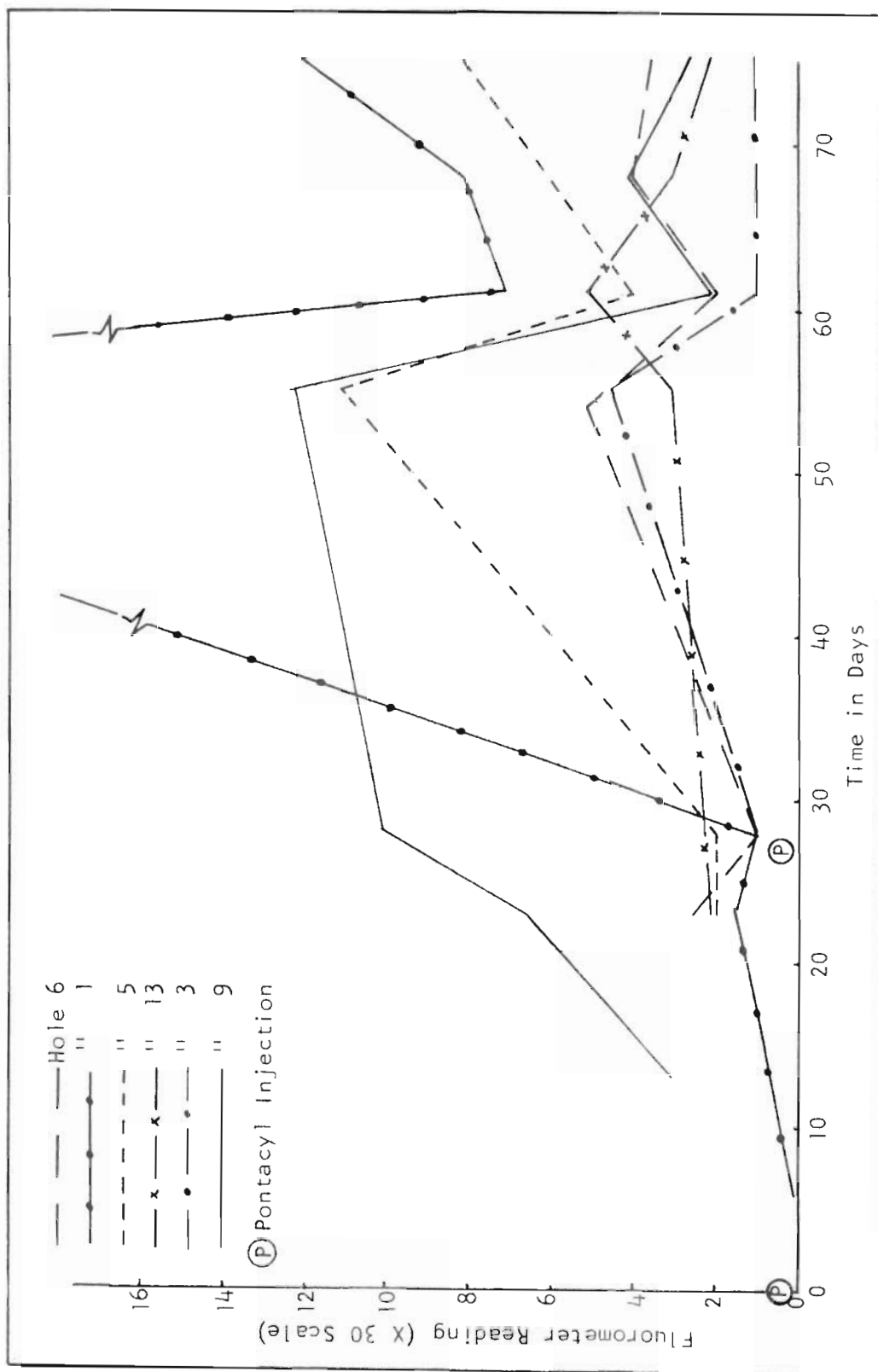


Figure 49. Relative dye concentrations at sample holes versus time since injection of dye (Robinson Site).

Fluorescein readings are not shown because contamination of all the sampling points occurred. This contamination resulted from using the pond water to backflush the cased sampling holes at the time of casing and also at a later time. This pond water was later found to have a very high fluorescein background.

FD&C Red #2 was injected for study under field conditions because of its favorable performance under laboratory conditions. It was not detected at any of the sampling points.

All hydraulic conductivity tests were run in cased holes. The results of these tests, using auger-hole theory, were erratic and no conclusions can be made as to the hydraulic conductivity.

The quantity of flow from the drainage tile continually decreased from about 1 gallon per minute to about 1/4 gallon per minute as the pond elevation lowered. This was because the hydraulic gradient and the area available to flow decreased as the water in the pond lowered.

### Lolo Site

The Lolo Pass Site was chosen for extensive tracer tests because: (1) United States Forest Service personnel had drilled patterns of holes for a seepage study they were making, (2) it was located far enough from civilization so that the radioactive isotope tritium could be used without danger, and (3) Forest Service personnel could help collect samples. This site was located in the Lolo National Forest 9 miles east of Lolo Pass in the NW1/4 sec. 24, T. 38 N., R. 16 E.

The air photograph (Figure 50) shows the general layout. Two sections of the study blocks as laid out by the Forest Service were used. Figure 52 shows these blocks, the holes used for injection and sampling, and a typical soil profile and soil characteristics.

The areas consisted of a relatively shallow soil mantle of decomposed granite underlain by granitic rock. The surface of the site was littered with large rounded boulders. Channeling of the abundant groundwater probably occurred to a great extent through and around these boulders. Most of the flow was in the decomposed granite near the bedrock and around the boulders. The groundwater level was very near the ground surface in the spring and early summer months, but it dropped in the later summer and early fall months to about 2 to 5 feet below the ground surface.

Tracer tests at Lolo Pass involved the injection of fluorescein, pontacyl, and tritium, combined in one solution, into the two injection holes (Figure 51). The first injection was made July 15, 1965. Subsequent injections involving only fluorescein and pontacyl were made at times shown in Figures 53 and 54.

Hydraulic conductivity tests were made in some of the sampling holes after sampling had been discontinued. These holes, 3 inches in diameter and about 6 feet deep, were drilled by the Forest Service personnel for their study. Pipe, 3/4-inch diameter with perforations each foot of length, was installed in the holes and backfilled with a fine gravel.

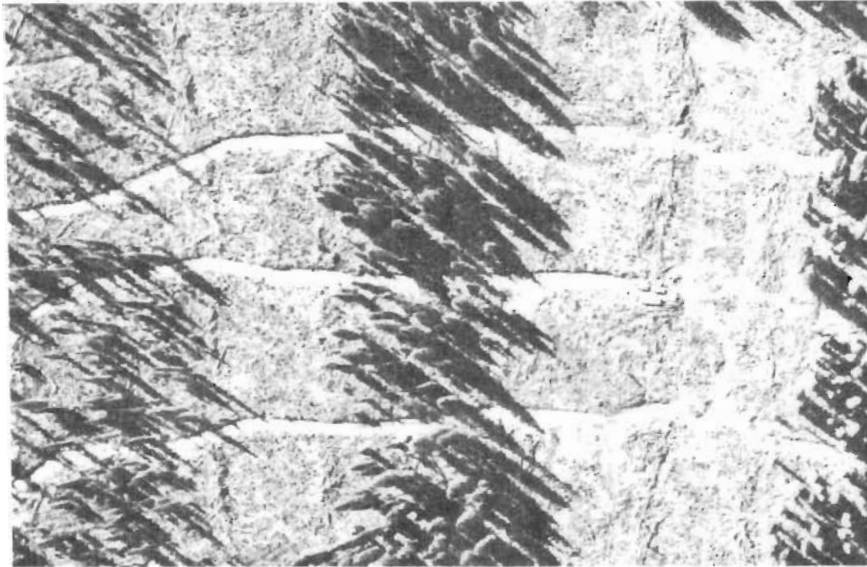


Figure 50. Air photograph of Lolo Site.



Figure 51. Dye solution injection at Lolo Site.

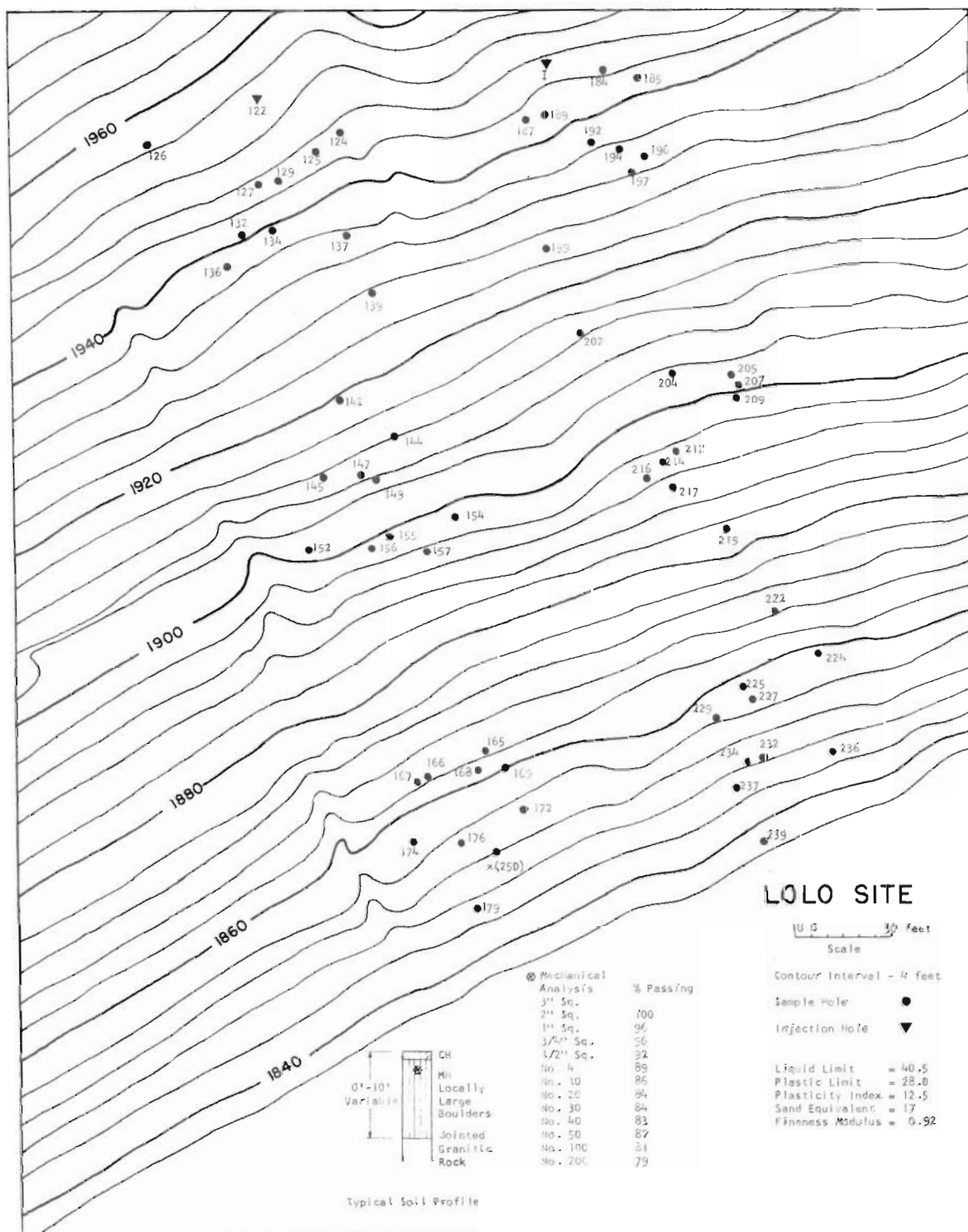


FIGURE 52. MAP OF LOLO SITE.

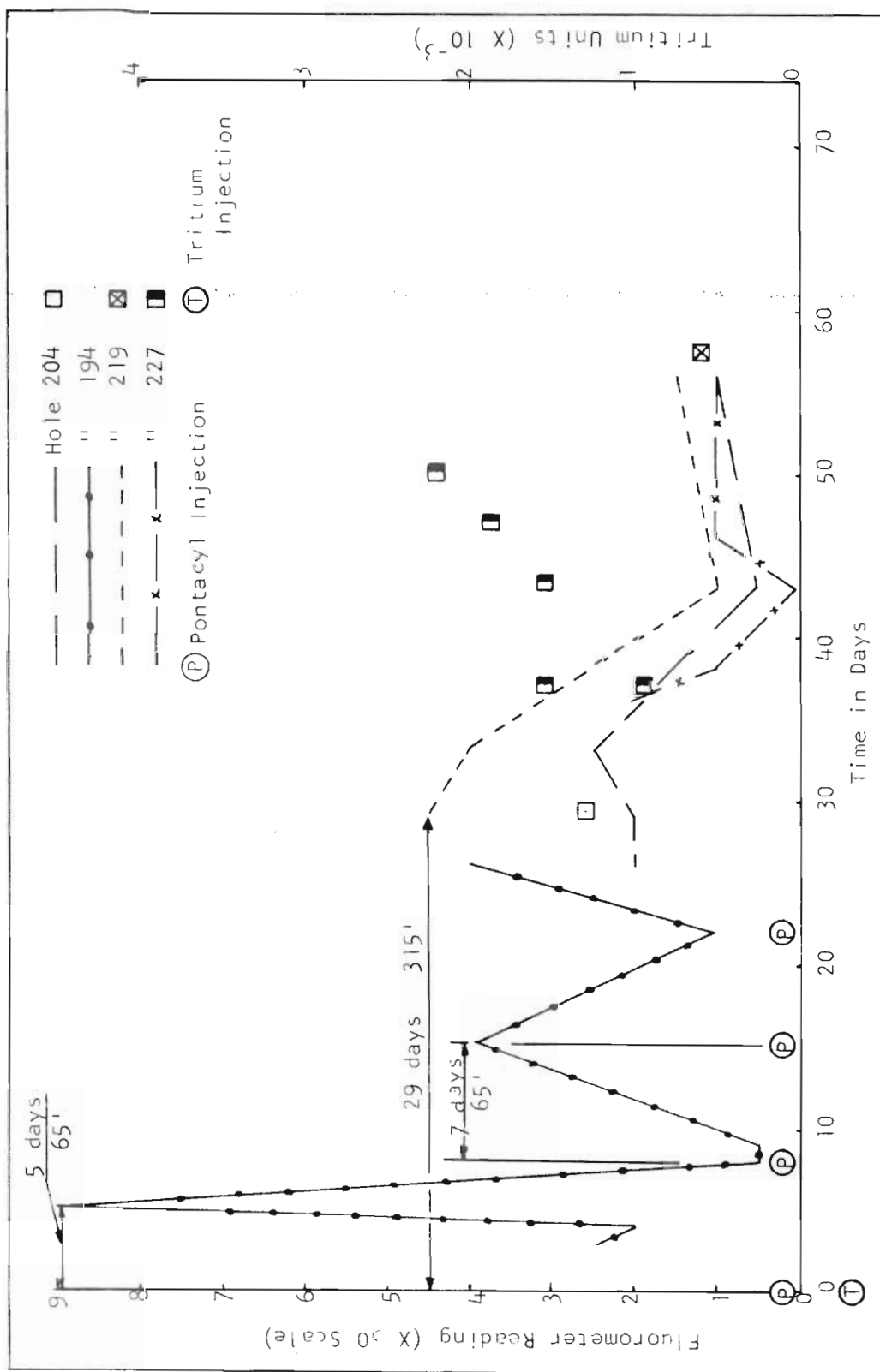


Figure 53. Relative dye concentrations at sample holes versus time since injection of dye (Lolo Site).

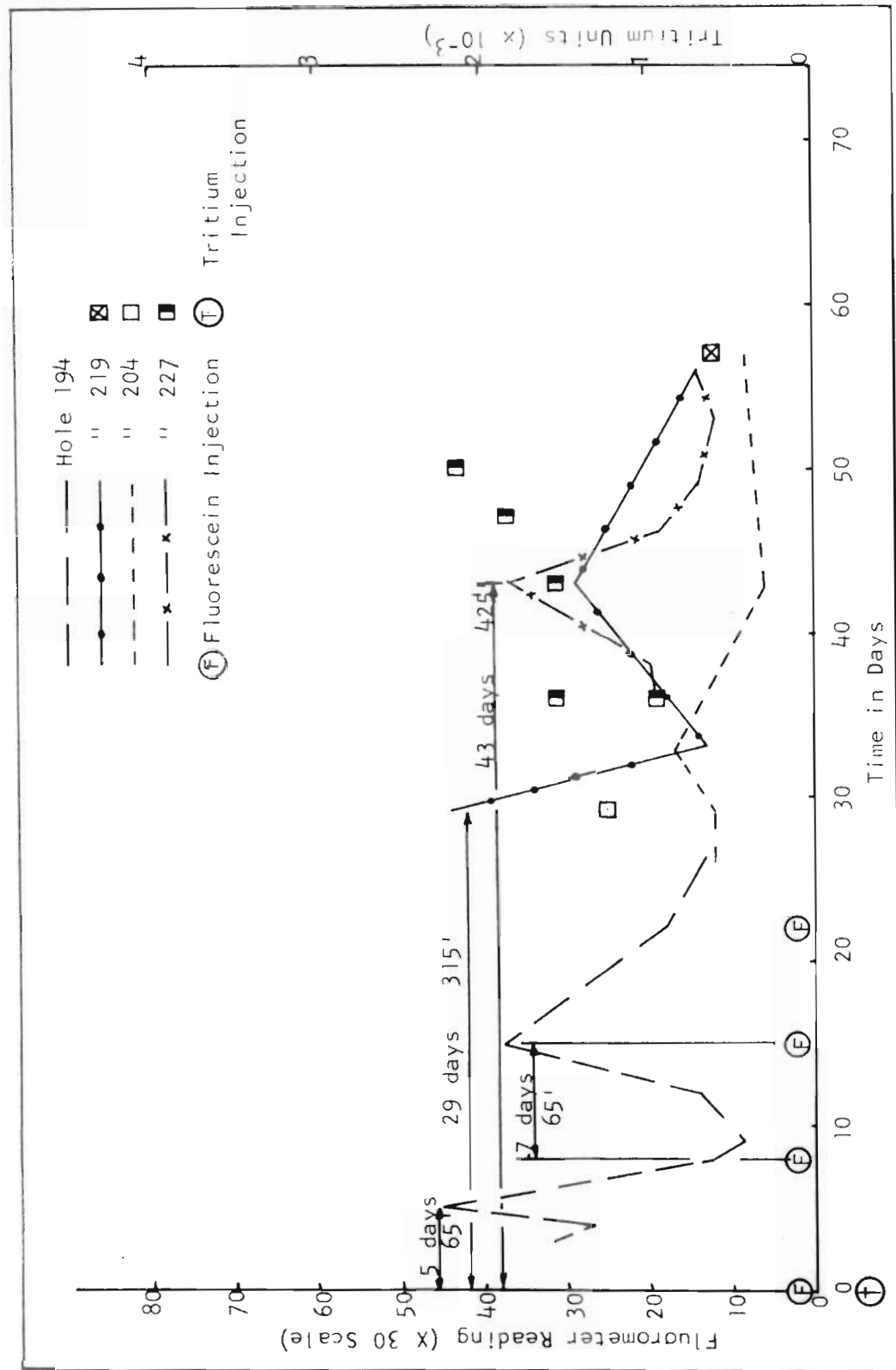


Figure 54. Relative dye concentrations at sample holes versus time since injection of dye (Lolo Site).

The Forest Service personnel had previously performed many hydraulic conductivity tests using the pumping test method outlined by Luthin (19) and credited to Hooghoudt.

The hydraulic conductivity values obtained by the auger-hole tests were inconsistent and they varied over wide ranges (from 0.1 feet per day to 15 feet per day). The average value of hydraulic conductivity as determined by Hooghoudt's pumping test was approximately 12 feet per day. The seepage velocity calculated from this average hydraulic conductivity was about 9 feet per day. The results of the pumping tests were reported to be within a narrow range and were thought to be quite accurate.

Results of the tracer tests are shown in Figures 53, 54, 55, 56, and 57. These results are very good in that definite peaks in tracer concentration were detected and the peaks for different sampling holes were directly correlated with the distance and direction from the injection holes. Also, definite peaks of dye concentrations are associated with the different injection times. The average velocity of pontacyl and fluorescein calculated from the occurrence of the dye concentration peaks at the sampling points was about 10.5 feet per day. A difference in the rates of movement of the two dyes was not evident.

Tritium was injected at a concentration of  $6.1 \times 10^6$  TU or 0.02  $\mu\text{C}/\text{ml}$ . Samples were collected for tritium analyses by drawing water into a plastic tube with a surgical pump and then forcing the water out of the tube into a sample container. This method was similar to that used to collect the samples for dye analyses. The main difference was in the amount of sample collected.

The cost of commercial analysis for tritium in water samples is about \$40 to \$90 per sample depending upon the concentration and the number of samples to be analyzed. This eliminated the possibility of commercially analyzing the many samples. Therefore, 15 samples, collected from holes near the injection point, were analyzed at the University of Idaho by the Tolbert method (see Appendix B for details). Duplicates of six of these samples were analyzed by the Atomic Energy Commission, Idaho Falls, Idaho, to give a check on the analyses performed at the University. Subsequently, 93 additional samples were analyzed by the Atomic Energy Commission, some of which were duplicates.

The samples analyzed at the University contained tritium; however, the concentrations were near or below the lower detectability limit of the available equipment which created a question as to how reliable the values were. When these results were compared with those from the A.E.C., the unreliability of the University results was further recognized. However, the tritium analyses data from the A.E.C. did compare very well with the data of the dye tracer tests in that samples showing the highest dye concentrations corresponded to samples showing the highest tritium contents. The tritium concentration of the samples analyzed by the Atomic Energy Commission ranged from less than 612 TU to 6732 TU.



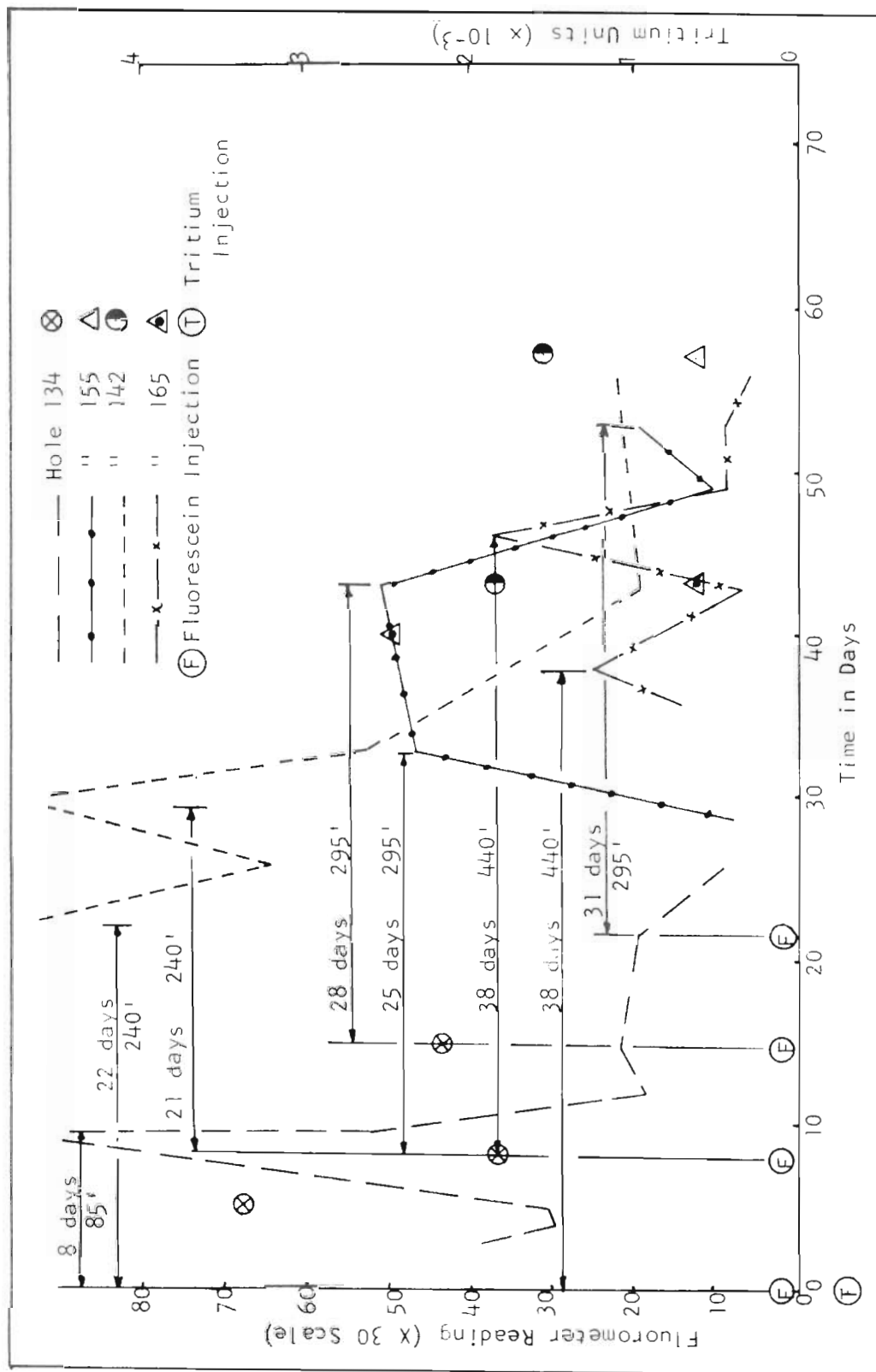


Figure 55. Relative dye concentrations at sample holes versus time since injection of dye (Lolo Site).

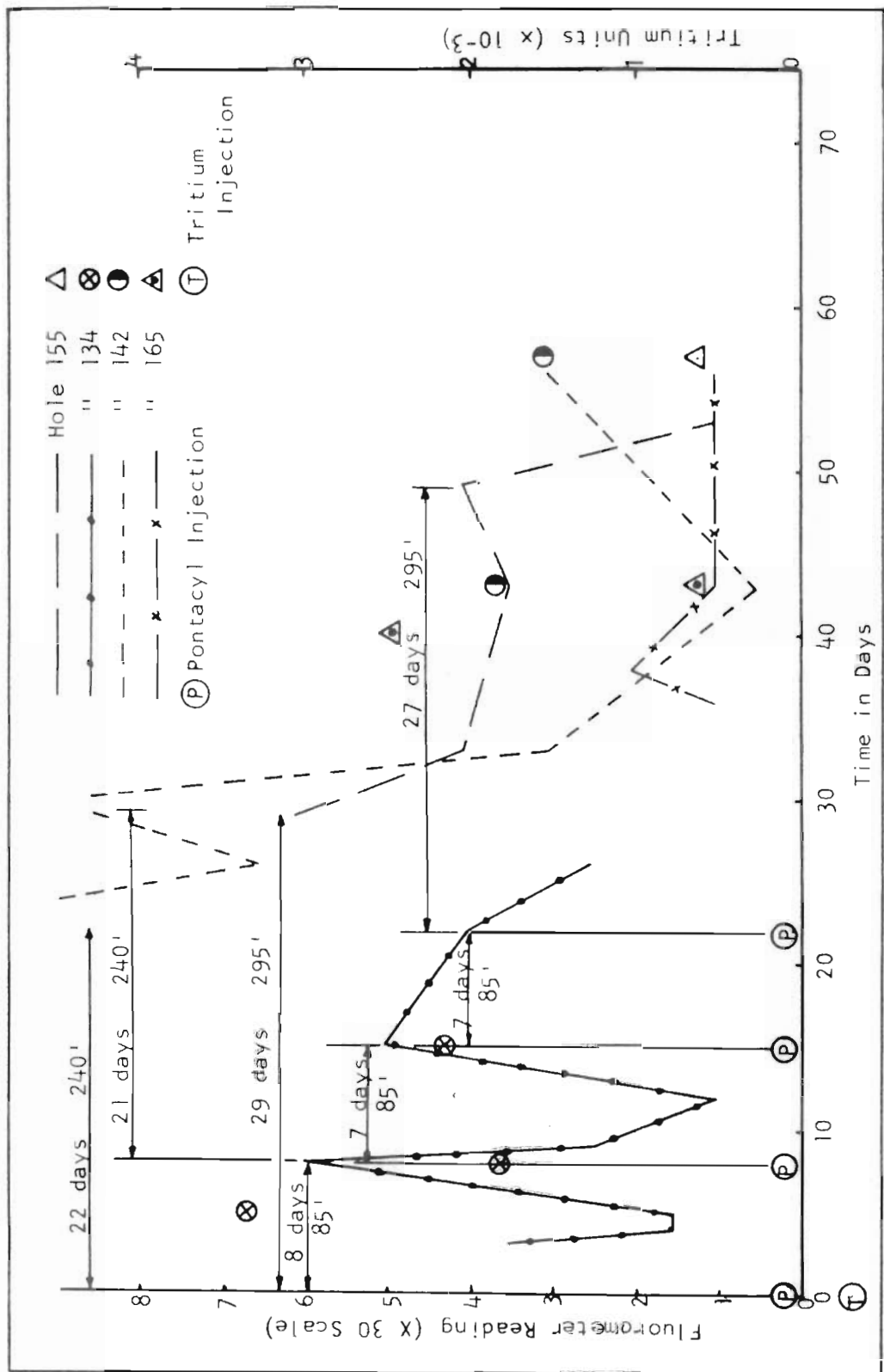


Figure 56. Relative dye concentrations at sample holes versus time since injection of dye (Lolo Site).

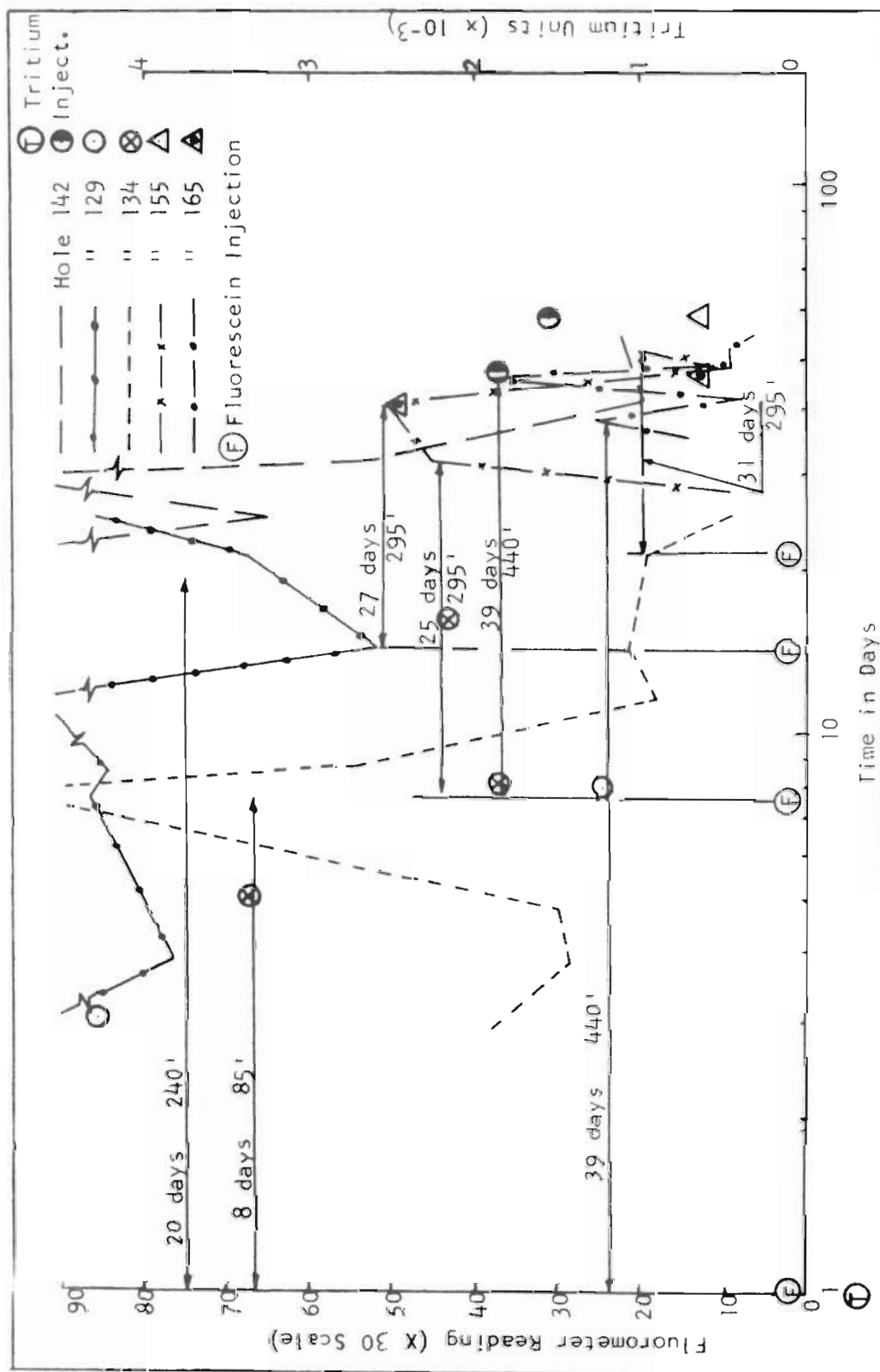


Figure 57. Relative dye concentrations at sample holes versus time since injection of dye (Lolo Site).

## CHAPTER V

### ANALYSIS OF RESULTS

#### I. LABORATORY EXPERIMENTS

Even under the best circumstances, field conditions cannot be exactly duplicated in the laboratory for experiments concerned with groundwater movement. Soil columns, carefully prepared prior to passing the dye solutions through them, were utilized to allow comparisons between the different dyes rather than to obtain absolute results. The soil column tests were valuable in establishing which dyes were the most suitable for tracing groundwater through various types of soil. The seepage of the dye solution in unsaturated flow through the soil columns showed that some dyes were adsorbed or filtered out of the solution in the first few inches of travel. The soil and dye properties that caused this adsorption or filtration were not studied. However, it was realized that physical and chemical properties of the soil particles and of the dye tracers were important in tracer retention.

By analyzing the results of the laboratory experiments, it was evident that almost any of the dyes would adequately trace groundwater through coarse sand or gravel, but only a few of the dyes would adequately trace groundwater through silts and clays. Possibly the two most important reasons for this are: (1) the fine-grained soils have smaller pore sizes which means that greater filtration of suspended dye does occur, and (2) the fine-grained soils have much more surface area to contact and adsorb dye.

It was evident that nonuniformity of prepared samples occurred. Certain soil columns showed much slower seepage than supposedly identically prepared samples. Upon vertically slicing these columns after testing, horizontal layering, voids near the cylinder walls, and other undesirable nonuniformities were noticed. These nonuniformities would probably balance out over the series of tests so that on the average no one dye would have more favorable test conditions than another. Since all of the tests were performed in the laboratory with a nearly uniform temperature of the room and of the water used for testing, temperature effects were not considered in the analyses.

Some soil columns were prepared for quantitative experiments using FD&C Red #2, pontacyl, fluorescein, and rhodamine. Typical curves presented in Figure 14 show the concentration ratio as the dependent variable plotted against time as the independent variable. The graph shows that the concentrations of all dyes slowly increased to a peak and then gradually decreased for many hours. This is explained by the following important facts:

1. The first detection will be of dye carried along the most direct and fastest route.
2. Many of the pore spaces are not interconnected or at least are not effective in transmitting bulk flow.
3. Diffusion from the concentrated seepage solution to the films of water bound to soil particles and to water in the pores not effective in bulk flow will occur because of a concentration gradient.
4. Diffusion of the dye from the bound water and the water in the pores not effective in bulk flow to the seepage water will occur as the highest concentration front passes.
5. The pore sizes will affect the rate of flow.
6. The dye does not necessarily move at the same rate as the groundwater.

Through proper sampling schedules in field experiments, similar curves could be constructed for determination of the tracer velocity. In the present study, the average velocity of the dye was calculated by noting the time that the dye concentration reached its peak value. Other investigators who have studied groundwater tracers have used the first arrival, the inflection points of the bell shaped concentration ratio curve, the maximum concentration, and other points to calculate the velocity which they considered to be representative of the groundwater movement.

A curve of concentration ratio versus time should be a bell shaped curve according to statistical theory. In the present studies the curves were not bell shaped, although some did approach that shape. Generally a concentration peak was reached after only about 30 per cent of the dye had passed through the soil column which caused a much longer tail on the declining side of the curve than on the climbing side. At least part of the reason for this is that the dye was retained by attraction to the soil particles, and until the concentration gradient became great enough to overcome the attraction, the dye could not diffuse back into the seepage water. The reason that the concentration ratio curves of FD&C Red #2, pontacyl, and fluorescein were not more uniform and similar was attributed to nonuniformity of the prepared soil columns. The curve for rhodamine definitely shows that rhodamine is limited as a groundwater tracer.

The chelating agent "blue cheer" served to keep the dye in solution but at the same time it caused a decrease in the seepage water velocity. The slowing can be explained by noting that a detergent molecule is designed to be attracted to dirt or in this case the soil particles. This molecular attraction increases the drag force between the moving liquid and the stationary soil particles, hence a slower movement. How "blue cheer" kept the dye in solution is not understood.

## II. FIELD EXPERIMENTS

### Hydraulic Conductivity

The auger-hole method of determining hydraulic conductivity proved suitable in soils that would sustain a uniform diameter hole drilled deep enough to penetrate the water table. Fairly consistent results were obtained at the Clyde Site, even under conditions of different diameter holes and different depths of the holes below the water table.

The auger-hole method is based on bailing water from the hole to cause a residual head. This allows the hydraulic conductivity to be determined under saturated conditions, using the native water. However, the same theory would apply to a slug test if the residual head was small in relation to the total original depth of water in the hole. Should the residual head be large, at least part of the flow from the hole would be in the unsaturated zone, which would result in values of hydraulic conductivity being too small. Also, introducing a foreign water at possibly different temperatures could have some effect on hydraulic conductivity.

The preceding statements seemed to hold true in the present study. Many slug-injection auger-hole tests were run and compared with the conventional bail auger-hole tests. The comparisons showed that hydraulic conductivities were about one and one-half times larger for the bail test than for the slug test. The reason for this was that the residual head in the slug tests was large in comparison with the normal depth of water in the hole. Therefore, an important portion of the flow from the hole was through the unsaturated soil which showed a lower hydraulic conductivity. Also any suspended material in the slug water would tend to clog the flow passages and thus reduce the hydraulic conductivity.

At the Fleiger Site, the auger-hole hydraulic conductivity values varied considerably. This was primarily caused by nonuniform diameters of the test holes, although unsaturated flow due to using the slug-injection method probably accounted for some of the variation.

At the Lolo Site, the auger-hole hydraulic conductivity tests were very inconsistent and could not be correlated with information from the pumping tests or the tracer tests. Since the holes were of uniform diameter and the gravel surrounding the pipe was very pervious, these holes were analyzed as auger holes. However, difficulties were encountered. Different degrees of "plugging" occurred in the gravel that surrounded the pipe. This plugging resulted from overland flow and groundwater flow carrying soil particles into the gravel. More bailings before hydraulic conductivity tests may have opened the pores of the surrounding gravel and soil which would have resulted in more consistent hydraulic conductivity values from the auger-hole method.

Nearly all hydraulic conductivity values obtained by performing tests in the cased holes were found to vary so much that they were considered unreliable. Part of the variation was caused by plugging of the wellpoints. Another cause of variation was in defining the hole

diameter to be used in the calculations. This was especially true where the holes were predrilled and then cased, in which condition, the casing size and the sluffing of the hole sides affected the hole diameter.

Slug-injection and bailed-well transmissibility tests are not satisfactory for application to most landslide problems. The transmissibility values determined at many various sites were inconsistent and even if they had been consistent, accurate determination of the aquifer thickness was difficult, and in many cases impossible to make. The inconsistency of the results of these tests was due in part to the test conditions not fulfilling the assumptions of the method, such as: (1) the casing was not perforated for the entire thickness of the aquifer, (2) the tests were not restricted to confined aquifers, (3) the residual head was not small in relation to the depth of water in the hole, and (4) the data did not always plot on a straight line.

The attempt to correlate velocities determined by the auger-hole hydraulic conductivity with velocities determined by tracer techniques was generally unsuccessful because sites at which the auger-hole tests gave reliable values were the sites at which tracer tests were unreliable and conversely.

### Tracers

The tracer experiments yielded positive results at some sites and negative results at other sites. The gradient of the groundwater table proved to be an important criterion in estimating how effectively the tracer would perform. Steep groundwater-table slopes tend to cause larger groundwater velocities and in turn probably less dispersion.

In some cases, sample concentrations were very low or negligible, because of dispersion. Dispersion had occurred to the extent that the tracer concentration had been lowered to values below the detection range. In other words, just because the tracer material was not detected at a sample point did not mean in all cases that the tracer had not reached the point.

A background of fluorescein existed at every site as can be seen on the graphs of fluorometric readings versus time. These background readings were graphically accounted for by ignoring the minor fluctuations that occurred around the background readings and just considering fluorometric readings that were definitely not background for velocity determinations. A pontacyl background did not exist at any of the sites, but because of its low fluorometric readings, small fluctuations were noted due to lack of preciseness of balancing and reading the fluorometer.

At both the Fleiger and the Hoodoo Valley Sites it was found that fluorescein dye had a definite "plugging" effect on the soil passages and on the wellpoint screens. This "plugging" effect was evidence that fluorescein would be filtered or adsorbed out of solution by the soil particles. This information along with information gained from laboratory experiments showed that a loss of tracer due to filtration or adsorption occurred and must be considered in a tracer program using any of the dyes.

Tracer tests at the Fleiger Site and at the Hoodoo Valley Site showed a movement of dye between the injection holes and sampling holes when an artificial gradient was imposed between the holes. But under the normal water-table gradient the tracers did not move to the sampling holes. This is quite possible considering the low hydraulic conductivity values and the normal water-table slope which yielded calculated seepage velocities less than 0.1 foot per day.

Water in sample holes at both the Hoodoo Valley and the Clyde Sites was contaminated during heavy rains. How the contamination actually occurred at the Clyde Site is not known, but at the Hoodoo Site it definitely was due to flooding of the injection hole and some of the sampling holes. Contamination by the wellpoints and casing caused inaccurate readings at Hoodoo. The contamination resulted from previous use of some of the casing and wellpoints in injection holes at other areas. Even though the wellpoints and casing were soaked and rinsed, the dyes still remained on the metal. Steam cleaning was resorted to, but satisfactory cleaning was still not accomplished. Contaminated wellpoints used in sampling holes caused high fluorometric readings at first, but as the dye from the wellpoints went into solution and was diluted by the seepage water the fluorometric readings decreased.

At most of the remaining sites definite patterns of fluorometric readings can be correlated with injection sequences and with the distance of the sampling points from the injection points. The graphical presentation of the data allows interpretation of the fluorometric readings more readily than tabulated data.

Tracer studies at the Orofino Site were quite conclusive in some respects. Both fluorescein and pontacyl dye were detected at down-gradient sampling points. The tracers moved at least three times faster between some injection points and sampling points than others. This probably happened because: (1) a more direct route was followed, (2) groundwater flow was through a sand lense, or (3) the sampling point was located along the same flow line as the injection point.

The Kennedy Ford Site yielded good results when tracing infiltration and seepage water with pontacyl dye. Unsaturated flow was traced for approximately 10 feet at which point the infiltrating rain water entered the saturated condition and the movement of this seepage water was traced for about 30 feet. The heavy rain transported some pontacyl dye overland part of the distance from one injection trench to the sample points and this accounts for detection of the dye at some holes much sooner than at other holes. The reason that hydraulic conductivity values were so low as to be of no use was believed to be in part the smearing of the hole sides while drilling and not enough care in developing the holes before the tests were run.

Results of the Brammer Site tests show that both fluorescein and pontacyl effectively traced groundwater over 100 feet. However, the three concentration peaks that occurred 14 days after the fluorescein injection in Figure 36 are unexplainable unless contamination occurred in either the sampling or transporting equipment or else errors were made in the laboratory analyses.



The Ahsahka sites, where the distance between the injection points and the sampling points was less than 100 feet, gave sporadic results for the tracer tests. This was the result of using an improper dye of which the characteristics were unknown. Another reason for inconclusive results at the Ahsahka sites was that the time interval between sampling was too long in some cases which allowed concentration peaks to pass the sampling points without detection.

The Huff and Robinson Sites, near Priest River, were very different and the results obtained reflected this difference. A tracer movement of about 70 feet per day occurred at the Huff Site. This velocity was much higher than at any of the other sites, and it could be considered as very high for groundwater movement. However, the underlying aquifer material of clean sand and the steep hydraulic gradient could readily effectuate this velocity. The Robinson Site results are inconclusive because of the contamination of sampling points with the pond water. Figure 49 shows that pontacyl was detected at some sampling points about 50 days after the first injection. This cannot be accounted for, unless contamination of the sampling containers occurred, because no detection was made at the drill holes which were much closer to the injection points.

Probably the most successful tracer tests were conducted at the Lolo Site. Fluorescein and pontacyl proved to be effective in tracing the groundwater movement. Water movement was traced for over 400 feet and the velocity of the tracer movement was about 10.5 feet per day. The velocity determined by using the hydraulic conductivity of 12 feet per day, as determined by the pumping tests, and the water-table slope of 0.23 feet per foot was 2.76 feet per day. This superficial velocity when modified by the porosity (estimated 30 per cent), gave a seepage velocity of about 9 feet per day. The comparison made here is only approximate because the value of porosity was assumed. The velocity determined by tracers was the velocity of the tracer, not necessarily the velocity of the water, because as shown in laboratory tests the tracer may be delayed and may not move as fast as the water. No difference was noted in the rates of movement of fluorescein and pontacyl.

Results of the effectiveness of tritium as a tracer were not as conclusive as were the dye results. The main reasons for this were that an inadequate number of samples was obtained and, because of the remoteness of the site, the times of sampling did not always correspond to periods of maximum or minimum tritium concentration.

The good comparison between the tritium results and the dye results for the samples analyzed by the A.E.C. shows that tritium probably was effective as a tracer. By using higher concentrations of tritium for injection, the equipment available at the University of Idaho for analysis by the method outlined in Appendix B probably would yield reliable data.

In certain cases samples were not collected soon enough to detect the first arrival or possibly even the maximum concentration of dye that passed the sample hole. This was evident at several holes where the first sample gave the highest fluorometer reading.

## CHAPTER V

### CONCLUSIONS AND RECOMMENDATIONS

#### I. CONCLUSIONS

Much data were collected from laboratory and field experiments. Upon analysis of these data the following conclusions were made:

1. Tracers can be used advantageously to delineate groundwater movement in active or potential landslides under certain conditions. Each location must be analyzed separately by considering: (1) water-table gradient, (2) hydraulic conductivity, (3) soil properties, and (4) the amount of time available for the tracer tests.
2. A step-wise, or multiple tracer approach, is useful in determining the over-all groundwater flow patterns for an area. This approach utilizes several small-scale tracer tests to determine the direction and rate of groundwater movement for short distances which when correlated and extrapolated depicts the over-all pattern. This method should especially be used in soil-water systems in which the tracer would be adsorbed or filtered out in relatively short distances, or it could be used primarily as a method to save on the amount of time required for a tracer program for a given area.
3. The amount of tracer necessary to "mark" water for later detection in tracing groundwater movement is dependent upon dispersion, adsorption, filtration, water-table gradient, porosity of soil, distance water is to be traced, velocity of water, and detection limit of equipment. Each site must be individually analyzed before the amount of tracer can be estimated.
4. The data from tracer tests should be presented graphically to allow a complete and proper analysis to be made.
5. The Turner, Model 110, Fluorometer works very well in determining the concentration of fluorescent dyes and is capable of detecting concentrations as low as 1 part in 10 billion.
6. The Fisher Electrophotometer is not very satisfactory for determining the concentration of the non-fluorescent dyes used in groundwater studies because its detection limit is not much better than visual detection or about 10 ppm.

However, within its range, it allows concentration values to be determined whereas visual inspection does not.

7. All of the dye tracers were to some extent adsorbed or filtered out of solution by fine-grained soils.
8. Any of the tested tracers are capable of tracing water movement through coarse-grained soils.
9. Pontacyl, fluorescein, rhodamine, and FD&C Red #2 were superior to the other dyes. Rhodamine was limited by adsorption and filtration while FD&C Red #2 was limited because equipment to detect low concentrations was unavailable. This left fluorescein and pontacyl as the two most favorable of the tested dyes.
10. Fluorescein background concentrations were present in groundwater at all of the test sites which created the need for very careful analyses.
11. Pontacyl background concentrations were either very low or were not present in the groundwater at any of the test sites.
12. Cross contamination must be guarded against when sampling or relocating wellpoints and casing. Dye should not be taken to field sites in powdered form; it should be transported in solution.
13. Tritium can be reliably detected in concentrations as low as about  $1 \times 10^5$  TU with the equipment available at the University of Idaho, as compared with detection limits of less than 50 TU by commercial testing apparatus.
14. Tritium can be used to trace groundwater, and the University of Idaho is licensed to use tritium of sufficient concentrations to allow detection in the collected samples with the present equipment.
15. The auger-hole method is superior to the transmissibility methods for determining in-situ hydraulic conductivity in most cases because: (1) the diameter of the hole and the depth that the hole penetrates the water table does not substantially affect the results, (2) the thickness of the aquifer is not needed, and (3) the auger hole does not have to extend to an impervious layer. The one disadvantage of the auger-hole method is that it is not applicable to a confined aquifer.
16. It is likely that many of the attempts made by Department of Highway's personnel to trace groundwater movement failed, not because the tracer did not follow the movement, but rather because the available detection techniques were not adequate.

17. The most important factors that limit a tracer program are dispersion and adsorption or filtration of the tracer material.
18. The tested dyes do cause temporary "plugging" of the soil pores.

## II. RECOMMENDATIONS

The analysis of results and the conclusions have led to the following recommendations:

1. More extensive laboratory tracer tests should be made to determine if a correlation between soil properties such as gradation or fineness modulus, the hydraulic gradient, and the effectiveness of tracers can be made.
2. Detailed field tracer studies should be made at two or three carefully selected field sites. These studies should include information on rainfall, infiltration, temperature of the air and groundwater, hydraulic conductivity, porosity, water-table elevation and slope, flow rate, direction and quantity, the distance of the soil mass movement and how it is related to water-table elevations.
3. The step-wise or the multiple tracer approach should be further studied to determine the accuracy and feasibility of extrapolating the small-scale tests to even larger areas.
4. More field tests should be made concerning dispersion of the tracer in different types of soil and with different natural water-table slopes so that the amount of tracer to sufficiently "mark" the water for later detection can be calculated.
5. More tests should be made using tritium as a tracer; especially using higher concentrations, but in no case should the concentration exceed the maximum permissible concentration for radioactive materials as set forth by the A.E.C. A feasibility study of using tritium to trace water in connection with landslides and other groundwater problems in areas where public acceptance is required should be made.
6. Tracers could be used in the study of unsaturated flow under field conditions; especially infiltration and percolation down to the water table.
7. Proven tracers should be used in an attempt to empirically establish better methods for determining hydraulic conductivity in holes cased with various types of casing.
8. Laboratory experiments should be made to test the effect of different acids on fluorescent dyes to determine if the acids could be used to clean up contaminated equipment.

9. The Department of Highways should utilize dye tracers (fluorescein and pontacyl) to a greater extent in both landslide problems and in damage claim problems concerned with groundwater. A fluorometer should be purchased and its use incorporated into the tracer program.

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## REFERENCES CITED

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## APPENDIX A

TABLE 1

## WATER LEVEL RECORDS, OROFINO SITE

DATE	Drill Holes and injection trenches (See Figure 29)										NOTES
	3A	9A	8A	1A	7A	6A	X	Y	11A	I1	
(1964) Oct 30 Dec 4 (1965) Feb 2 9 16 25 Mar 5 11 18 30 Apr 12 20 24 27 May 5 12 20 26 Jun 1 9	12.5' 7 5 5.4 5.8 6.4 6.6 6.9 7.0 6.5 6.0 4.5 6.5 7.0 7.5 7.8 7.9 8.1 8.0	Dry Dry 1.1' 1.2 1.1 1.4 1.5 1.7 2.0 1.3 1.3 1.0 1.7 2.4 4.3+ - - - -	Dry Dry 1.9' 2.5 - 2.5 3.01 3.20 3.02 2.41 2.10 2.63 3.42 5.06 6.56 6.55 7.50 8.89	Dry Dry 2.0' 2.0 1.9 2.2 2.5 2.7 3.4 3.1 2.5 2.0 2.70 4.0 6.0 6.4+ - - -	Dry - 0.2' 0.2 0.2 0.2 0.3 0.5 0.8 0.2 0.1 0 0.1 0.7 2.6 4.0 2.9 5.0 6.8	- 9.5' - 6.0 5.7 - - - 8.0 6.9 6.4 F(100gm) 7.0 8.1 10.5 11.0 9.0 11.5 Dry	Dry Dry 5.3' - - - - - - - - - - - - - - -	Dry - 1.7' 1.8 2.3 - - 3.3 3.4 3.5 3.5 - 3.6 3.72 3.8 3.9 3.96 4.05 4.05	- - 1.25' 1.90 2.15 - - - 4.5+ 5.2 8.7 - - - - - - -	Fluor.        Pont.  P(100gm) F(50gm)	Recorder-8A F(6A), P(11A)  Rain P(6A) New Fluor.  8A (?) 9A Dry 1A Dry  Stream flowing in ditchline dried up. Heavy recent rain
18 24 30	7.9 8.2 8.6	- - -	9.54 10.0 10+	- - -	6.7 7.2 8.2	Dry Dry Dry	- - -	4.2 4.28 4.2	- - -		

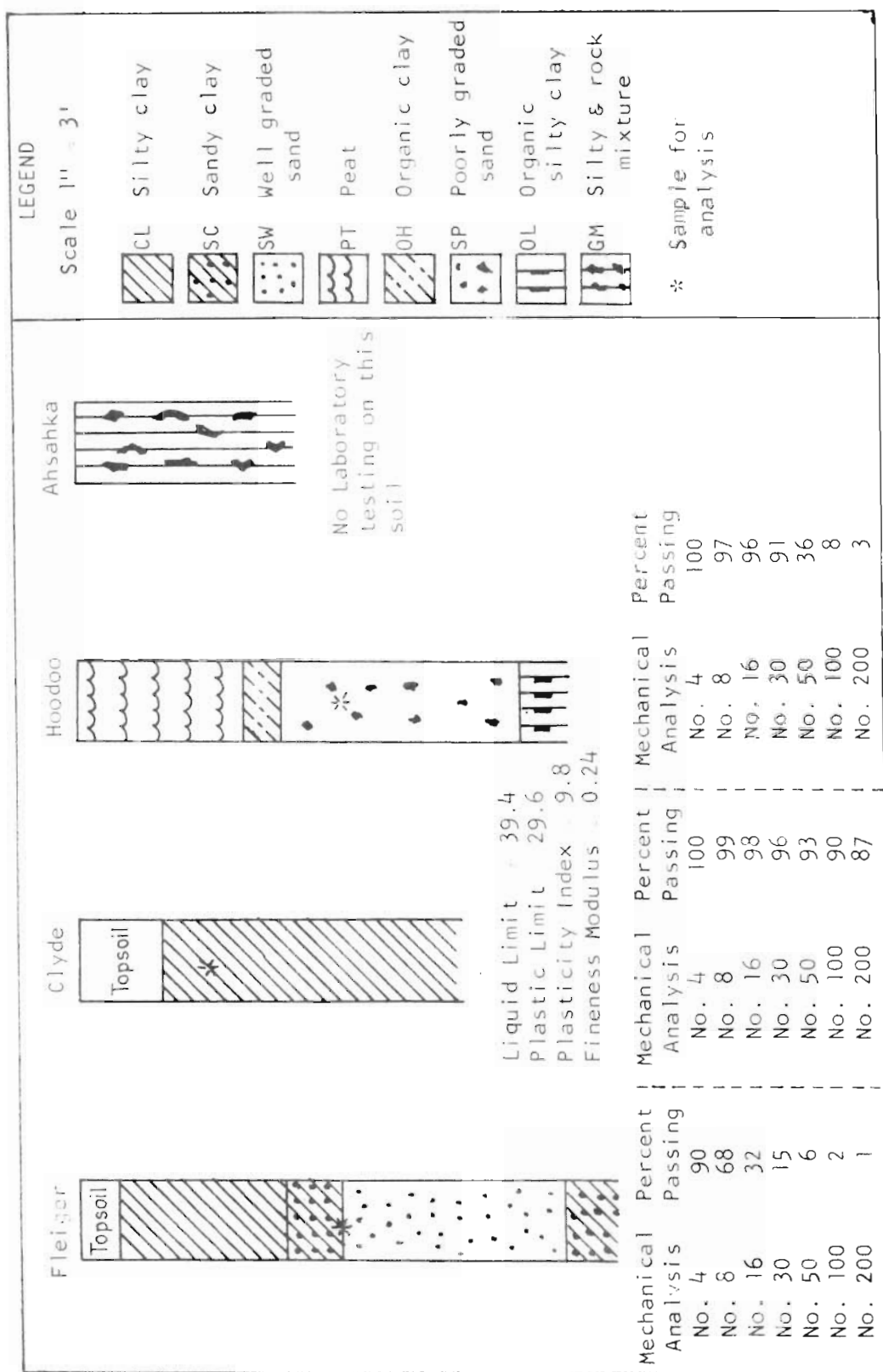


Figure 58. Typical soil profiles of Fleiger, Clyde, Hoodoo Valley, and Ahsahka Sites.

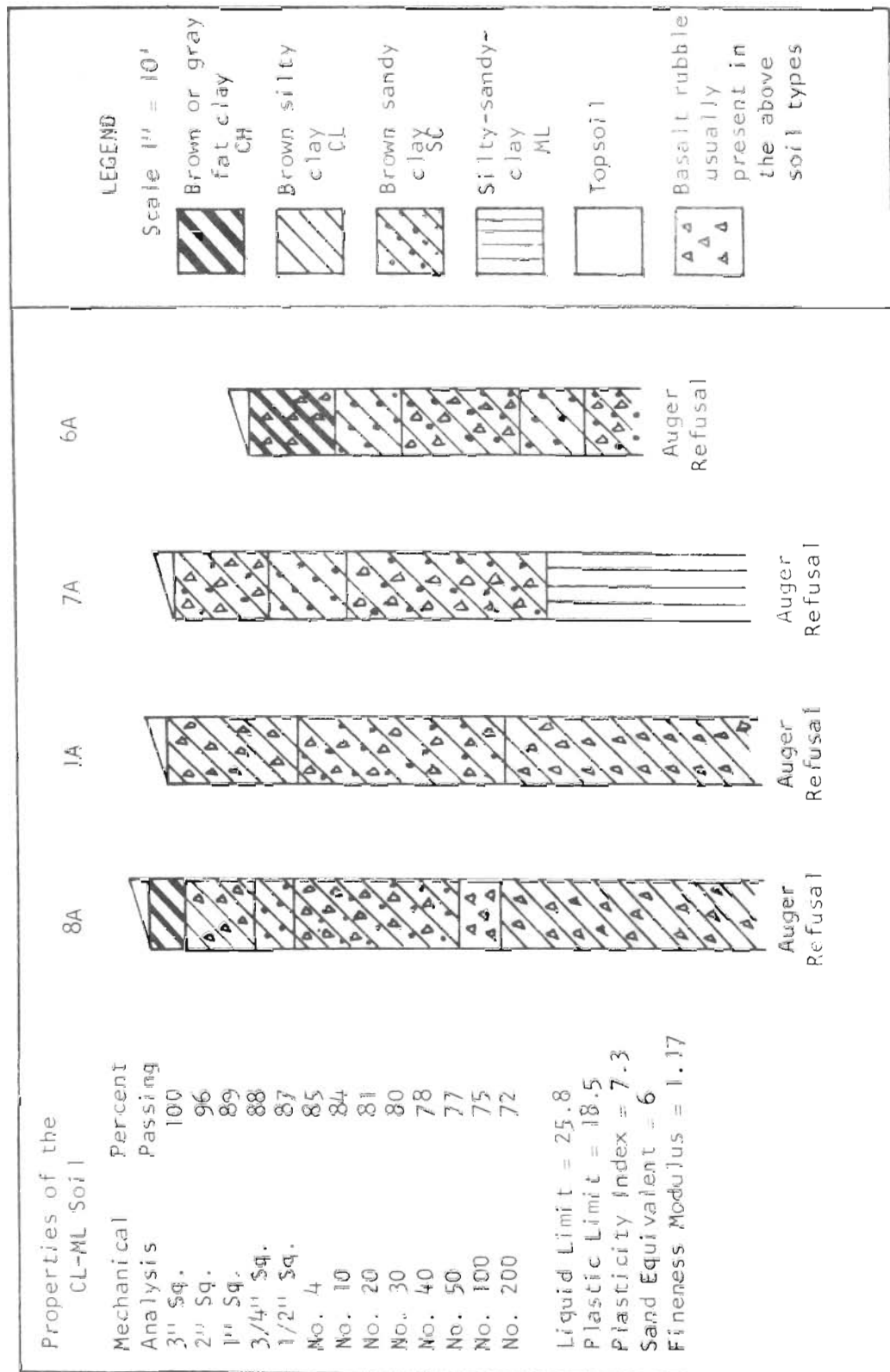


Figure 59. Soil profiles at the Orofino Site.

## APPENDIX B

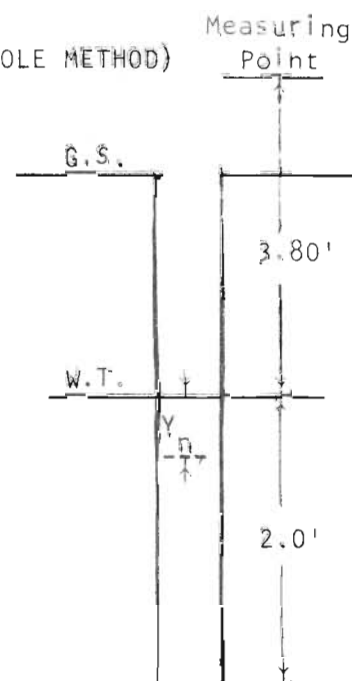
## HYDRAULIC CONDUCTIVITY TESTS (AUGER-HOLE METHOD)

Date 7 Nov 64  
 Hole No. D-3  
 Location Clyde Site  
 Diameter 3" Radius 0.125'  
 Type of Test: Slug      Bail X  
 Depth of water in hole 2.0  
 Original depth to water 3.80

Test Data

$$Y_0 = 0.34$$

$$.8Y_0 = .272$$



Time (sec)	$\Delta t$ (sec)	Depth (feet)	Residual Head $Y_n$ (feet)	$\Delta Y_n$ (feet)
0		4.14	0.34	
10	10	4.10	0.30	.04
20	10	4.06	0.26	.04
30	10	4.02	0.22	.04
40	10	3.99	0.19	.03
50	10	3.96	0.16	.03
60	10	3.93	0.13	.03

Calculations

$$\bar{Y}_n = \frac{0.34 + 0.26}{2} = 0.30 \text{ feet}$$

$$\bar{Y}_n/r = \frac{0.30}{0.125} = 2.4$$

$$\overline{\Delta t} = 10 \text{ seconds}$$

C (from chart of Maasland and Haskew) = 2350

$$\overline{\Delta Y_n} = \frac{.04 + .04}{2} = .04 \text{ feet}$$

$$K = C \times \frac{\overline{\Delta Y_n} r}{\overline{\Delta t}} = 2350 \left( \frac{.04}{10} \right) = 9.4$$

$$H/r = \frac{2.0}{0.125} = 16$$

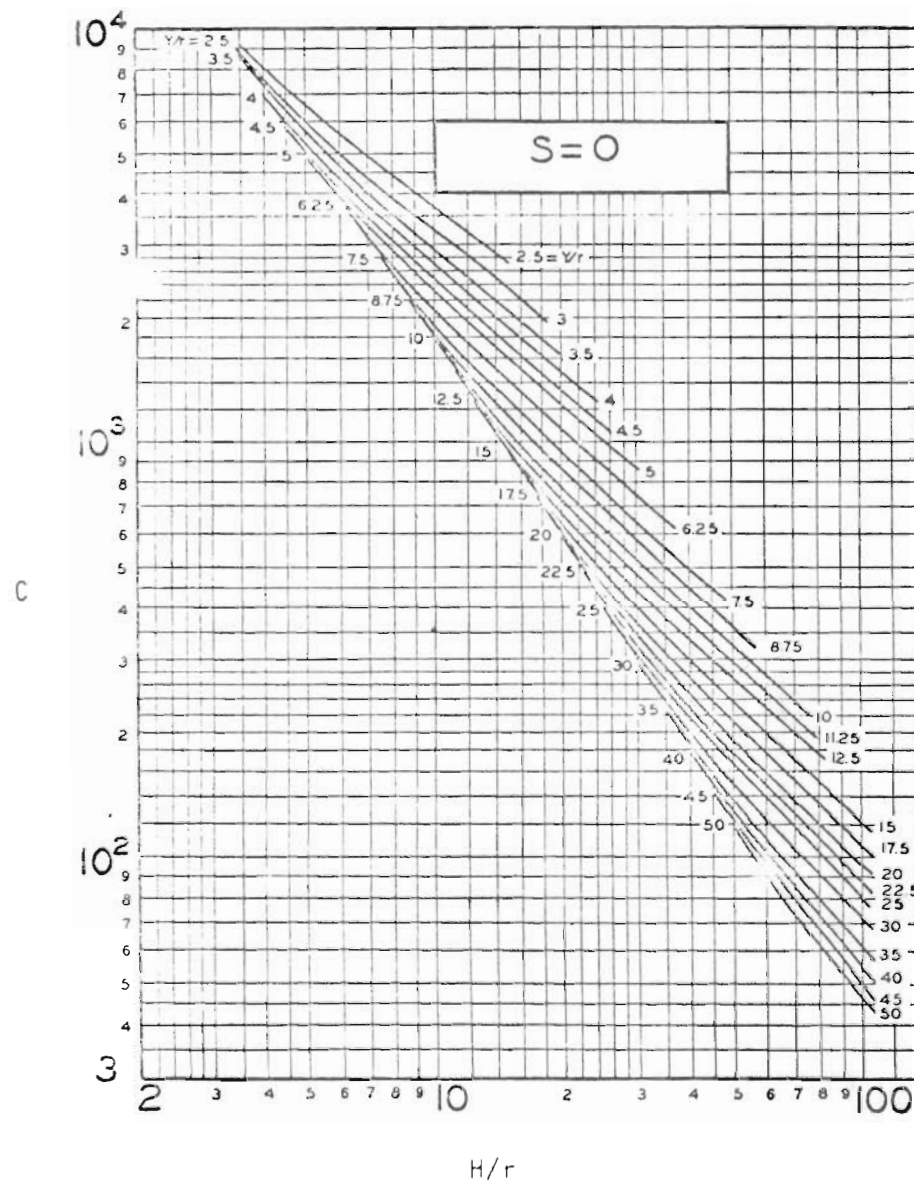
$$K = 9.4 \text{ ft/day}$$

$\bar{Y}_n$  = Average distance from static water table to the water surface in the hole during the test period.

$\overline{\Delta Y}$  = Average incremental rise during incremental time intervals.

$\overline{\Delta t}$  = Average incremental time interval.

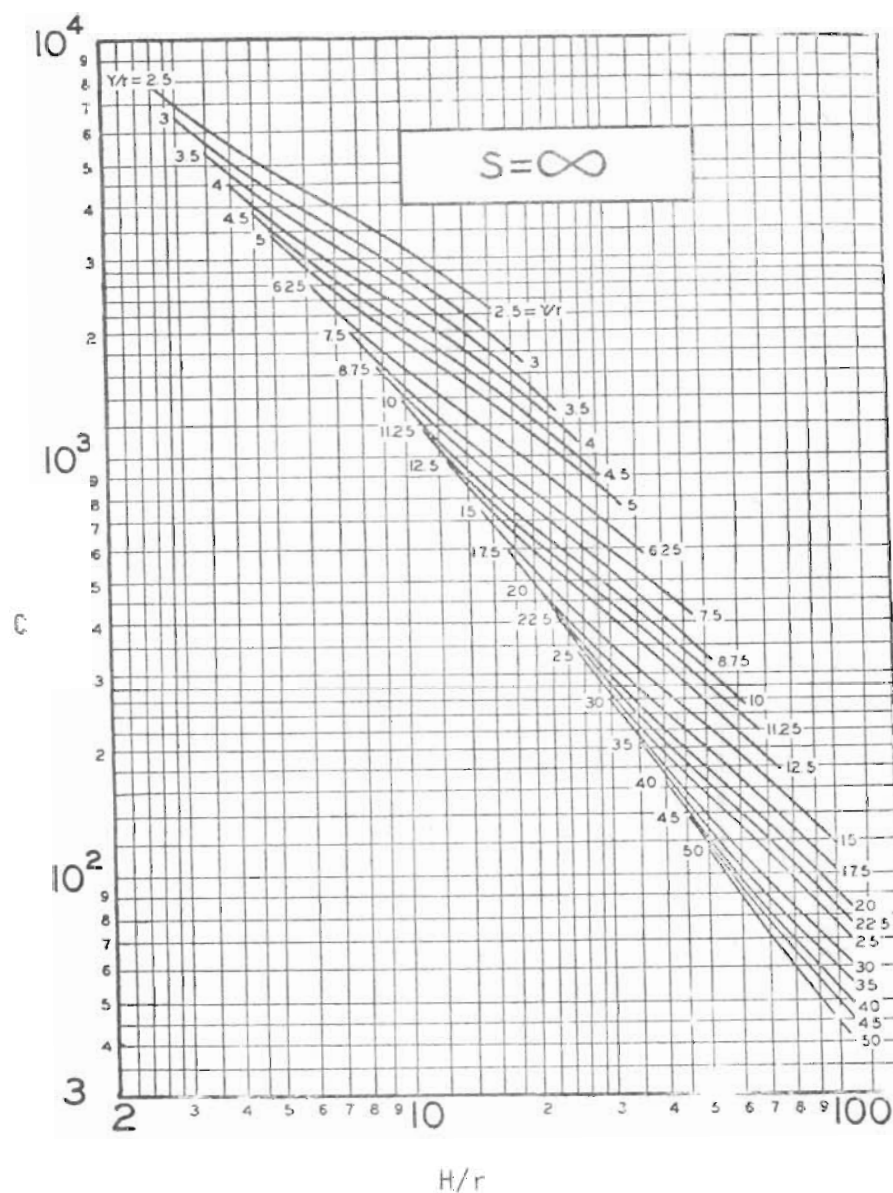
Figure 60. Auger-hole method of calculating hydraulic conductivity.



Values of  $C$  vs  $H/r$  for various constant values of  $y/r$ .  
 It is assumed that the auger hole is in homogeneous isotropic soil, while  $s=0$ ; i.e., the hole just reaches a horizontal impermeable layer.

Figure 61. Maasland and Haskew chart for determining hydraulic conductivity by the auger-hole method (See Reference 20).





Values of  $C$  vs  $H/r$  for various constant values of  $y/r$ .  
 It is assumed that the auger hole is in homogeneous soil, while  $s=\infty$ ; i.e., the impermeable layer is at appreciable depth below the bottom of the hole (for practical purposes  $s \geq H$ ).

Figure 62. Maasland and Haskew chart for determining hydraulic conductivity by the auger-hole method (see Reference 20).

## LABORATORY ANALYSES OF SAMPLES

Field-collected water samples were taken to the laboratory for analyses. Because some of the samples were very turbid and because this turbidity influenced the fluorometer and electrophotometer readings, the samples were allowed to sit for two or three days in a dark place. The suspended material had then settled to the bottom so that the water for analysis was relatively free of turbidity. Since this project was mainly concerned with relative rather than quantitative readings, a consistent pattern was followed in preparation of the samples for the analysis.

### Fluorometer

The procedure as outlined in the Model 110, Turner Fluorometer operating instruction booklet was followed. Blank water samples were collected from each test site for background readings. One very important aspect of the fluorometric analysis is that different dyes require different filters to be placed in the fluorometer before readings are taken. This would lead one to believe that if two dyes, requiring different filter sets, were present in one sample, they could be independently determined. It was found that this was true to a certain extent. Fluorescein dye will not cause fluorometric readings when pontacyl and rhodamine filters are used, but pontacyl and rhodamine will cause fluorometric readings when fluorescein filters are used.

The fact that there was a semi-independent detection of these tracers was utilized extensively by injecting the tracers either separately or in combination at coincident or non-coincident times. However, it should be realized that the value of the multiple tracer approach in any site is dependent upon the ingenuity of the person designing the program.

### Electrophotometer

The Fisher Electrophotometer operations manual was followed in the analysis of non-fluorescent dyes. Separate filters were used to give relative readings between blank samples and samples collected throughout the sampling period.

### Tritium

Talbert (30) presents a method for "Assay of Tritium in Water." His method was followed in the present study and is quoted here for reference:

#### Assay of Tritium in Water

##### Introduction

Water and lithium aluminum hydride ( $\text{LiAlH}_4$ ) react vigorously and exothermically to produce hydrogen gas. This process provides a convenient method to convert water into a gas so that tritium may be analyzed with an ionization chamber-electrometer. The procedure is capable of assaying small amounts of tritium

when the ionization is measured by the rate-of-charge method. It is important to reproduce carefully the procedural steps in an assay method where an isotope effect may enter, as in the generation technique here.

There are several chemical reactions in this procedure. The relative importance depends on temperature, mixing, and abundance of water in the generation mixture.



### Equipment

- 1- Ionization chamber, 500 to 1000 cc.
- 1- Cary Vibrating Reed Electrometer, Model 31 or 32
- 1- Recorder (See Section I)
- 1-  $10^{12}$  ohm resistor and resistor holder
- 1- Vacuum manifold assembly as shown in Figure 63.  
Include the generation equipment shown.
- 1- Mechanical vacuum pump e.g. Welch Duo Seal Model 1400B
- 1- One liter of dry diethyl carbitol (Union Carbide Corp.) saturated with lithium aluminum hydride. About 30 ml of this solution is needed per assay.  
Tritium water, unknown and/or standards with a specific activity of about  $1\mu\text{c}/\text{ml}$ . One ml will be used per assay.  
Dry ice; isopropyl alcohol; large-mouth picnic vacuum flasks in 1 qt. and 1 pt. sizes; ball and socket clamps, etc.

### Experiment

Assemble the hydrogen generation equipment shown in Figure 63. The lithium aluminum hydride solution container is a two-necked 100 ml flask. Vent the vacuum pump exhaust and the mercury manometer reservoir flask to a hood.

Evacuate the ionization chamber and fill it with hydrogen to a pressure so that excess hydrogen bubbles out of the mercury manometer. Repeat this several times to flush out any residual activity. Measure the background ionization current for the hydrogen filled chamber. Use the rate-of-charge method.

Attach the ionization chamber to the manifold. Put 20 ml of the  $\text{LiAlH}_4$  solution in the generator flask and about 1 ml tritium water in the sample holder. Grease the joints with silicone stopcock grease and assemble the unit. Freeze the water with a dry ice-isopropyl alcohol bath. Evacuate the entire system. Place another dry ice-isopropyl alcohol bath around the cold trap.

Close the stopcock to the vacuum pump. Warm the tritium water sample and add the water slowly to the carbitol solution by rotating the water sample holder. When sufficient hydrogen is generated to fill the entire system so some bubbles come out the mercury manometer, close the ionization chamber valve. Evacuate the residual hydrogen in the vacuum manifold, remove the  $\text{LiAlH}_4$  solution and decompose any excess reagent in the hood with isopropyl alcohol. Place the chamber on the electrometer and read the ionization current by either the rate-of-charge or the high-resistance-leak method. Caution: Treat  $\text{LiAlH}_4$  and its solutions as carefully as you would sodium metal. Do not put them in waste baskets or leave them sitting around, for spontaneous ignition of an open solution is possible in a wet atmosphere. Decompose all used solutions and flush them down a sink. Also be careful of the hydrogen gas and do not work with it near open flames.

#### Calculations

- 1) If the tritium water activity is known, calculate an observed ionization chamber constant in amps/curie.
- 2) Calculate the theoretical chamber constant in amps/curie.
- 3) Calculate the efficiency of the ionization chamber.

Tolbert's method as outlined above seems to be a fairly reliable method of analyzing tritium in water if the specific activity of the sample is from  $10^{-4}$  to  $10^6$   $\mu\text{C}$ . In the present study, glassware for tritium conversion (Figure 64), a Model 31 Cary Vibrating Reed Electrometer, and a Minneapolis-Honeywell recorder (Figure 65) were used for the conversion and analysis by the rate-of-charge method.

Information on reading the rate of charge is available in the Cary, Model 31, Operation Manual. Basically the procedure is: (1) mount the ionization chamber on the preamplifier unit, (2) connect batteries to the ionization chamber to establish the recommended voltage potential between the chamber walls and the center electrode, and (3) open the short switch and record the rate of charge for later calculations.

In the present study, diglyme was substituted for the carbitol solution as a medium in which to suspend the lithium aluminum hydride. Care must be taken to dry the diglyme before introducing the lithium aluminum hydride or a violent reaction may take place. Sodium metal can be used to dry the diglyme to the point that the lithium aluminum hydride powder can be safely introduced.

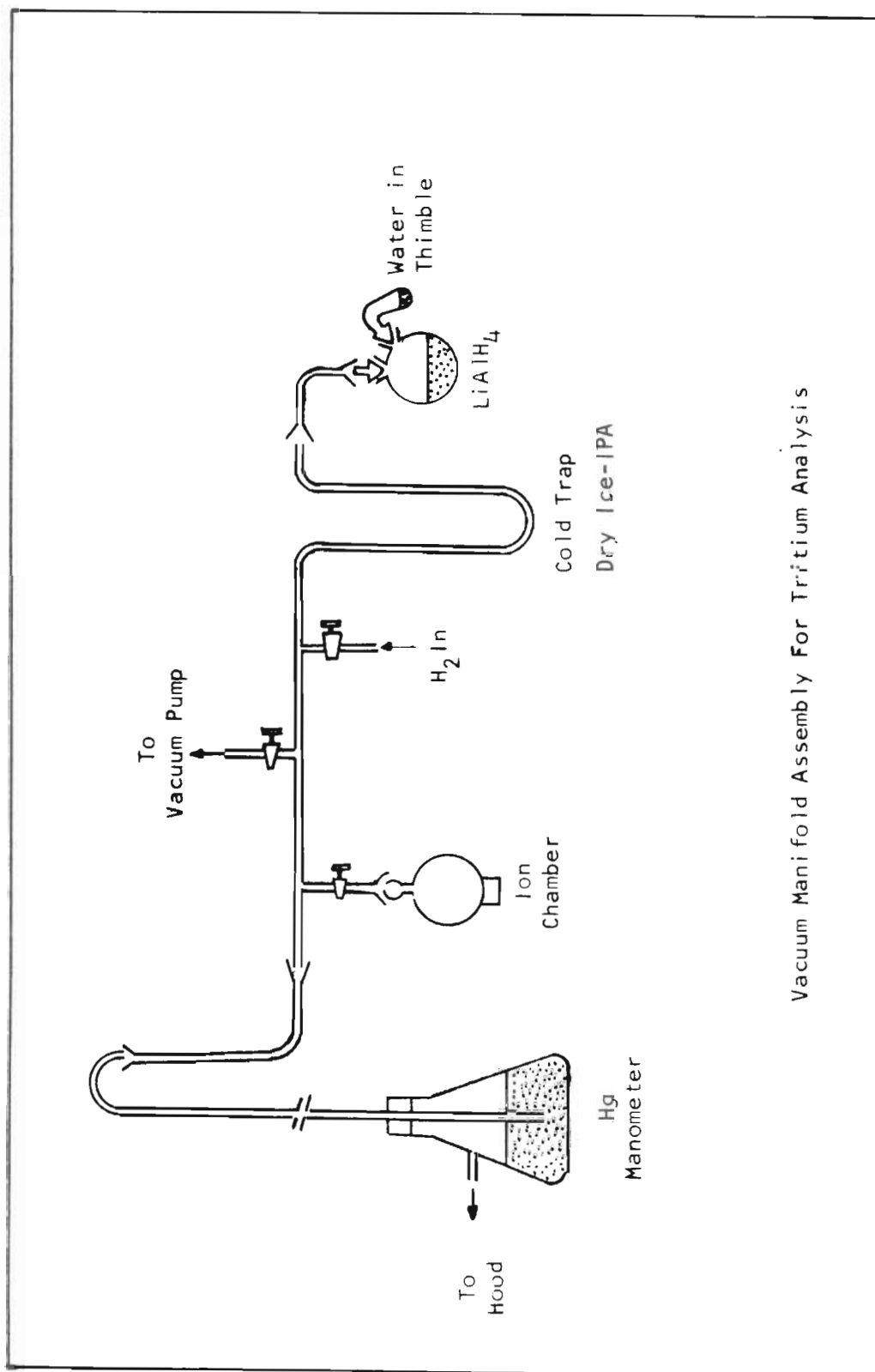


Figure 63. Schematic diagram of equipment for tritium conversion (See Tolbert, Reference 30).



Figure 64. Glassware for tritium conversion.

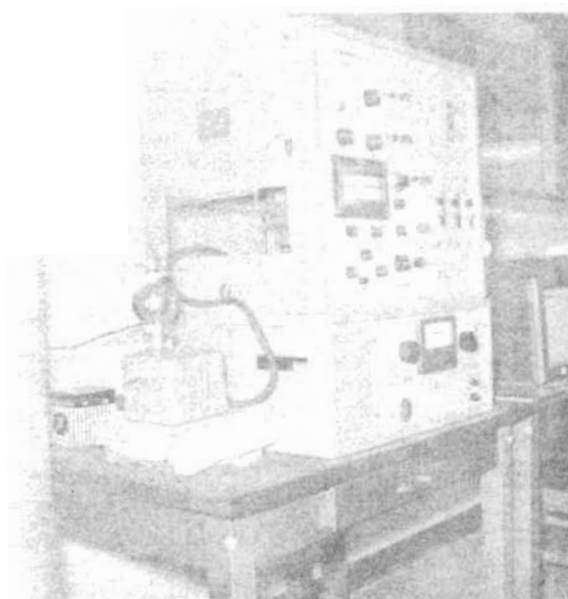


Figure 65. Cary, Model 31, Electrometer in operation.

TABLE 2  
FLUOROMETRIC READINGS (x-30) OF FLUORESCEN  
PLOT 1, HOODOO VALLEY SITE

DATE (1964)	HOLE LOCATION												
	13'NNW	11'NNE	9'NW	7'ENE	6'NNE	6'NNW	11'NNW	4'NNW	4'NNE	2'NNW	2'NNE	5'ESE	4'S
Sep 2			47	69	23	-						100+	
3	100+	-	35	74	17								-
10		100	33	75	45		72					100+	51
14		83	36	74	54		80					100+	55
16		86	29	55	34		50					96	31
18	47	100+	23	42	24		54					85	89
24	30	87	24	41	24		100+					83	78
Oct 1	61	-	24	38	24		100+					75	100+
14	39	91	30	33	20		67					77	72
27	26	87	32	35	42		70					50	51
Nov 13	-	100+	18	19	24		100+					28	100+
Dec 2	-	62	20	13	20		51					18	26
12	-	100+	14	12	21		100+					16	-

TABLE 3  
 FLUOROMETRIC READINGS (x-30) OF FLUORESCIN,  
 PLOT 2, HOOD00 VALLEY SITE

DATE (1964)	HOLE LOCATION							
	6'N	4'N	4'NE	4'NW	2'N	2'E	2'W	2'S
Sep 10			100+	100+	51	100+	37	
14		100+		100+	50	100+	37	
16		100		100+	100+	100+	53	
18		93		100+	38	100+	23	
24		83		100+	39	100+	30	40
Oct 1	39	79	27	76	31	100+	23	32
14	26	62	27	74	32	89	30	49
27	24	56	20	68	54	71	37	100+
Nov 13	27	43	19	71	100+	53	44	100+
Dec 2	30	47	21	71	100+	63	85	100+
12	25	50	17	68	100+	45	60	100+



TABLE 4  
 FLUOROMETRIC READINGS (x-30) OF PONTACYL AND RHODAMINE,  
 PLOTS 3 AND 4, HOODOO VALLEY SITE

DATE	PLOT 3								PLOT 4							
	HOLE LOCATION								HOLE LOCATION							
(1964)	6'N	4'N	4'NE	4'NW	2'N	2'E	2'W	2'S	6'N	4'N	4'NE	4'NW	2'N	2'E	2'W	2'S
Sep 25	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Oct 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
27	0	1	1	1	0	0	0	0	0	0	0	0	2	0	0	-
Nov 13	1	1	1	1	1	1	1	-	1	1	1	1	4	1	1	0
Dec 2	1	1	1	1	0	1	1	1	2	5	2	1	2	0	0	-
12	0	0	0	0	1	0	1	0	1	1	0	0	2	2	0	0

TABLE 5  
 FLUOROMETRIC READINGS (x-30) OF FLUORESCEIN,  
 CLYDE SITE, SHEET 1

HOLE NO.	DATE (1964)						
	9 Dec	10 Dec	11 Dec	14 Dec	19 Dec	21 Dec	24 Dec
1	22	20	19	17	21	20	42
2	20	19	16	15	17	20	44
3	32	29	25	23	20	26	65
4	26	25	25	21	24	28	33
5	18	18	18	14	21	18	38
6	14	18	15	16	16	100+	48
7	15	16	13	14	15	100+	100+
8	41	43	30	36	32	41	100+
9	14	17	13	12	18	15	100+
10	27	26	22	18	20	23	69
11	14	18	17	16	18	22	48
12	14	18	15	16	19	20	47
13	15	20	15	16	18	16	47
14		17	18	16	18	16	44
15	15	16	13	17	18	17	96
16	14	16	15	17	16	15	100+
17	24	23	23	20	19	20	45
18	22	21	19	18	20	20	34
19	42	56	48	55	47	52	100+
20	72	80	100	96	93	100+	100+
21		20	22	17	19	20	42
22		62	54	-	-	-	-
23		16	17	13	15	100+	66
24		37	30	30	28	33	79
25		35	31	30	24	21	45
26		21	20	18	18	17	39
27		23	19	15	19	16	100+

TABLE 6  
 FLUOROMETRIC READINGS (x-30) OF FLUORESCEIN,  
 CLYDE SITE, SHEET 2

HOLE NO.	DATE						
	28Dec64	5Jan65	13Jan65	3Feb65	8Apr65	7Jun65	25Jun65
1	23	20	18	28	20	20	-
2	30	26	22	28	21	81	-
3	30	23	20	28	57	83	-
4	26	30	19	25	62	100+	-
5	26	30	19	27	24	40	-
6	37	26	28	36	-	-	-
7	100+	72	52	56	53	83	-
8	100+	95	79	45	25	44	-
9	100+	91	79	90	87	100-	-
10	41	31	24	40	39	53	-
11	36	27	24	51	87	100+	-
12	31	39	31	52	89	100+	-
13	30	22	18	36	43	60	-
14	27	21	16	84	57	-	-
15	100	89	80	89	-	-	-
16	60	39	26	74	-	-	-
17	37	26	22	43	-	-	-
18	58	25	40	40	-	-	-
19	100+	79	80	85	-	-	-
20	68	57	50	100+	-	-	-
21	44	41	24	34	58	65	100+
22	-	58	40	51	18	56	100+
23	44	26	21	32	63	18	33
24	66	43	39	62	20	34	91.5
25	31	29	21	38	20	35	70
26	28	20	17	37	15	28	60.5
27	31	20	16	32	84	18	57

TABLE 7  
 FLUOROMETRIC READINGS (x-30) OF FLUORESCEIN,  
 CLYDE SITE, SHEET 3

HOLE NO.	DATE (1964)						
	9Dec	10Dec	11Dec	14Dec	19Dec	21Dec	24Dec
28		35	30	27	24	16	100+
29		36	32	34	30	46	50
30		27	26	21	22	20	55
31		33	61	30	39	51	45
32					21	21	50
33					21	26	33
34					26	21	40
35					25	19	41
36					27	30	36
37					26	15	38
38					27	20	38
39					27	19	41
40					36	23	37
41					26	33	33
42							

TABLE 8  
 FLUOROMETRIC READINGS (x-30) OF FLUORESCIN  
 CLYDE SITE, SHEET 4

HOLE NO.	DATE						
	28Dec64	5Jan65	13Jan65	3Feb65	8Apr65	7Jun65	25Jun65
28	100+	70	80	-	-	-	55
29	30	77	70	38	27	100+	100+
30	30	31	26	41	22	21	29
31	64	46	32	41	40	25	32
32	35	38	38	31	45	40	71
33	37	36	30	41	35	-	100+
34	28	32	26	36	39	57	100+
35	30	32	28	35	15	66	28
36	28	23	25	38	32	19	100+
37	32	44	44	41	28	79	100+
38	29	27	26	38	70	46	99
39	40	47	46	42	-	84	78
40	39	38	40	45	21	-	100+
41	27	42	35	57	48	78	29
42			25	28	20	43	61
43			37	25	19	43	43
44			47	38	-	-	35
45		38	52	38	-	-	41
46		38	22	38	23	19	27
47		44	34	49	-	29	60.5
48		46	34	46	-	74	70
49		38	18	21	-	-	24
50		22	17	21	-	-	36.5
51		19	22	33	-	-	-
52		38	30	33	-	-	-
53		38	22	24	-	-	-
54		35	22	38	-	-	-
55		36	35	33	-	-	-

TABLE 9  
 FLUOROMETRIC READINGS (x-30) OF PONTACYL AND RHODAMINE  
 CLYDE SITE, SHEET 1

HOLE NO.	DATE (1964)						
	9Dec	10Dec	11Dec	14Dec	19Dec	21Dec	24Dec
1	2	2	1	3	1	3	4
2	2	2	1	1	2	3	4
3	2	3	1	4	5	8	8
4	16	9	24	15	11	21	11
5	12	8	28	18	18	11	4
6	2	2	3	3	6	5	2
7	1	0	1	1	1	7	6
8	3	4	2	3	2	5	16
9	1	0	1	1	1	0	14
10	2	1	1	1	1	1	15
11	0	0	2	1	1	7	9
12	1	1	3	3	2	5	6
13	1	1	1	0	2	2	2
14	1	1	1	0	1	2	2
15	1	1	1	0	0	1	15
16	1	1	1	0	0	1	3
17	2	2	3	3	0	1	2
18	2	2	2	3	3	4	1
19	3	6	4	8	7	10	17
20	7	9	15	16	16	26	8
21		2	1	1	2	3	1
22		4	3	-	-	-	-
23		2	3	2	2	5	1
24		3	2	3	2	6	1
25		3	2	3	2	3	1
26		2	2	1	2	3	1
27		2	2	2	2	3	1

TABLE 10  
 FLUOROMETRIC READINGS (x-30) OF PONTACYL AND RHODAMINE,  
 CLYDE SITE, SHEET 2

HOLE NO.	DATE						
	28Dec64	5Jan65	13Jan65	3Feb65	8Apr65	7Jun65	25Jun65
1	1	2	1	10	2	1	-
2	2	2	1	11	1	1	-
3	30	9	6	10	2	1	-
4	14	3	8	4	4	2	-
5	2	3	3	1	2	1	-
6	1	1	1	3	-	-	-
7	6	3	2	2	2	1	-
8	13	11	10	3	1	1	-
9	13	8	9	9	4	1	-
10	7	6	4	5	2	2	-
11	5	4	3	5	4	2	-
12	2	3	3	4	4	1	-
13	1	1	2	3	2	1	-
14	1	1	1	4	2	-	-
15	8	7	7	7	-	-	-
16	0	2	1	1	-	-	-
17	0	1	1	1	-	-	-
18	7	1	3	6	-	-	-
19	15	9	5	8	-	-	-
20	10	6	5	5	-	-	-
21	3	1	1	3	5	1	3
22	-	1	1	2	2	1	3
23	1	1	0	2	2	1	3
24	3	1	1	5	2	1	3
25	3	1	1	3	1	1	3
26	3	1	0	3	1	1	3.5
27	2	0	0	2	1	1	2

TABLE 11  
 FLUOROMETRIC READINGS (x-30) OF PONTACYL AND RHODAMINE,  
 CLYDE SITE, SHEET 3

HOLE NO.	DATE (1964)						
	9Dec	10Dec	11Dec	14Dec	19Dec	21Dec	24Dec
28		2	2	3	2	3	1
29		2	2	3	2	3	1
30		2	2	2	2	3	1
31		5	8	4	3	9	1
32					2	3	1
33					2	2	1
34					2	2	1
35					2	2	5
36					1	1	3
37					1	1	3
38					1	1	3
39					1	1	3
40					1	2	3
41					1	3	2



TABLE 12  
 FLUOROMETRIC READINGS (x-30) OF PONTACYL AND RHODAMINE,  
 CLYDE SITE, SHEET 4

HOLE NO.	DATE						
	28Dec64	5Jan65	13Jan65	3Feb65	8Apr65	7Jun65	25Jun65
28	2	1	1	-	-	-	3
29	2	1	1	2	1	1	3
30	2	1	1	2	0	1	3
31	9	4	3	2	0	1	4.5
32	1	0	1	1	0	1	4
33	1	0	0	1	0	-	4
34	1	0	0	1	0	1	5
35	2	1	1	2	0	1	1
36	2	1	1	2	0	1	4
37	1	1	1	3	0	1	3.5
38	1	1	1	3	1	1	3
39	1	1	1	1	-	1	3
40	4	2	3	2	0	-	3
41	1	1	1	2	1	1	2
42		1	1	2	1	1	2.5
43		1	1	1	1	2	3
44		1	1	1	-	-	1
45		1	3	2	-	-	2
46		0	1	2	2	1	1
47		2	1	1	-	3	2.5
48		0	0	1	2	1	0
49		1	1	1	-	-	1
50		1	1	1	-	-	1.5
51		0	1	1	-	-	-
52		3	1	1	-	-	-
53		0	1	2	-	-	-
54		1	1	2	-	-	-
55		1	1	-	-	-	-

TABLE 13  
FLUOROMETRIC READINGS ( $\times 30$ ) OF FLOURESCIN,  
OROFINO SITE

DATE (1965)	HOLE NO.								
	3A	9A	8A	1A	7A	Cut No. 1 (7)	Cut No. 2 (6)	Cut No. 3 (11)	
Feb 2	29	50	40	17	100+	20	24	28	
25	25	40	28	12	100+	15	18	25	
Mar 5	22	31	28	10	82	14	19	28	
11	26	36	32	12	67	28	26	41	
18	22	35	30	14	47	29	23	24	
30	-	43	21	18	35	47	25	28	
Apr 12	23	41	20	13	36	15	18	21	
20	29	48	21	20	29	16	24	30	
27	24	33	19	10	23	17	18	30	
May 7						18	-	21	
12						29	-	-	
20						100+	-	29	
26						100+	-	52	
Jun 1						60	25		
13						42			
18									
25									

TABLE 14  
FLUOROMETRIC READINGS (x-30) OF PONTACYL,  
OROFINO SITE

DATE (1965)	HOLE NO.						Cut No. 1 (7)	Cut No. 2 (6)	Cut No. 3 (11)
	3A	9A	8A	1A	7A				
Feb 16	5	3	3	3	4		1	2	2
25	3	2	1	1	2		1	1	1
Mar 5	3	1	0	0	2		1	0	2
11	3	2	2	2	3		2	3	3
18	2	1	1	1	2		1	1	2
30	3	2	2	2	2		2	5	2
Apr 12	2	2	1	1	5		1	1	1
20	4	4	5	2	3		1	2	1
27	1	1	3	1	2		1	1	3
May 7							0	-	0
12							1	-	-
20							4	-	0
26							19	-	1
Jun 1							1	1	
13							2		
18									
25									

TABLE 15  
 FLUOROMETRIC READINGS (x-30) OF FLUORESCEIN AND PONTACYL,  
 KENNEDY FORD SITE

DATE (1965)	HOLE NO.											
	1	2	3	4	5	6	7	8	9	10	11	
Apr 22						45		28	20			F L U O R E S C E I N
May 1	26	68	100+	100+	57+	17+	21-	2	28.5	13+	30	
8	76+		68	80.5	76	39	17	9	12	19	32	
15	87	67.5	96	28+					29			
22	78		63	3	79		85		12.5	43	36	
29	70		92	93						96		
Apr 22						6		4	3			P O N T A C Y L
May 1	2	22	100+	100+	2+	1	1	0	2+	2-	4-	
8	225		28.5	28	100+	2	2-	1.5	2+	2-	4-	
15	32.5	29	28.5	77					1+			
22	18		29	1.5	100+		34+		1	3	0	
29	3		25	37						94		

TABLE 16  
FLUOROMETRIC READINGS (x-30) OF FLUORESCIN,  
BRAMMER SITE

DATE (1965)	HOLE NO.														REMARKS
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Apr 21		20													Hole No. 1 is a tile drain  18 May 65 150 grams in 13 and 14
24	27	32													
27	44	24	30	40	45	24	10	13							
May 8	48	25+	30	40	43	31	12-	14+							
12	40.5	21	31.5	40	46	41	8	14	15	15.5	21+				
20	27	20	29	53	83	40	9	16	11	27	16	18.5			
26	30	21+	29-	45+	55.5	39	16	22	13.5	30-	26	31			
Jun 1	26	24	23	29	=	45	40	53	32	13	38	26			
18	23	23.5	43	89	100+	45.5	8.5	10	13	18	22	11.5			
19	22	11.5	32	=	=	51	18.5	90	10	14	21.5	44			
25	52	40	38	-	62	56	39	25	18	13	37	15	15		
30							41	12.5	13	12	47	13.5	21.5	53	
Aug 12							100+	49.5	12.5	77					
19							100+	72	85						
26							100+	18+	20.5						
Sep 3							9+	53	7						

TABLE 17  
FLUOROMETRIC READINGS (x-30) OF PONTACYL,  
BRAMMER SITE

DATE (1965)	HOLE NO.														REMARKS
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Apr 21	1						1								Hole No. 1 is a tile drain 12Apr65 injection I <sub>1</sub> 20Apr65 100 gms I <sub>2</sub>
24	7	0													
27	100+	1	1	1	1	1	1	1							
May 8	89.5	1	1	1	1	1	1+	1+							
12	9.5	0	0	0	0	0	0	0	0.5	0	0				18May65 150 gms I <sub>1</sub> 150 gms I <sub>2</sub>
20	3+	1-	1-	1-	1	1-	0.5	0+	0+	1.5	3	0.5			
26	2	0	1	1	1	1	1	1	1	1	1	1			
Jun 1	2	2	2	2	-	2	2	2	2	2	2	2			
18	1.5	1	0	5.5	3.5	2	2	3	3.5	5-	4	4.5			
19	0	0	0	-	-	1	2	0.5	0	1	1	1			
25	1	1	1	-	1	1	1	1	1	0	1	1	1.5		
30							1	0.5	1	0.5	1	1	10	2	
Aug 12							16	3-	4+	10					
19							11+	2	8	1					
26							2	1-	4						
Sep 3							1	1+	0.5						

TABLE 18  
FLUOROMETRIC READINGS (x-30) OF FLUORESCEIN,  
AHSAHKA SITES

	DATE (1965)	HOLE NO.							REMARKS
		1	2	3	4	5	6	7	
H A L L	Apr 27	78	27	8	7	-	-	-	Initial Injection 20Apr65 100 gms I <sub>1</sub>
	May 7	38.5	57	28	13	8	10	-	
	12	23	27	8+	13-	5+	15	12	100 gms I <sub>5</sub>
	20	92	14-	34	22-	8	-	-	
	26	35	30	12	12	18.5	9	-	
	Jun 1	13	10	15	11	9	-	-	
	14	26	7	8.5	6	9	-	-	
	18	-	1-	4	-	-	-	-	
	25	80.5	14	42	10+	7+	-	-	
	30	34.5	11.5	-	7.5	-	-	-	
P O L E	Apr 27	30	22	35	10	-	-	-	Injections 20Apr65 and 24Apr65
	May 7	25	35	54	79	47.5	11	-	
	12	17.5	21.5	69	63	44	10.5	-	
	20	24	28	12+	-	-	-	-	
	26	20	24	24	18	29+	-	-	
	Jun 1	25	13	30	-	-	-	-	
S U T T O N	Apr 27	12	22	17	-	-	-	-	Injections 20Apr 65 and 20May65
	May 7	39	54.5	19.5	38	17	-	-	
	12	66	79	14	20.5	19-	-	-	
	20	21	13.5	20+	-	-	-	-	
	26	29	20	31.5	21	-	-	-	
	Jun 1	18	22	55	-	-	-	-	

TABLE 19  
FLUOROMETRIC READINGS (x-30) OF PONTACYL,  
AHSARKA SITES

	DATE (1965)	HOLE NO.							REMARKS
		1	2	3	4	5	6	7	
H A L L	Apr 27	5	2	2	1	-	-	-	Initial injection 20Apr65 1 <sub>2</sub> 100 gms 1 <sub>5</sub> 100 gms
	May 7	1	1.5	1+	1	0.5	1.5	-	
	12	1-	0+	0	0+	0+	0.5	0.5	
	20	10	1	4-	2-	0.5	-	-	
	26	0	0	1	0	0.5	-	-	
	Jun 1	1	1	1	1	1	-	-	
	14	1.5	0	0	0	1	-	-	
	18	-	0.5	0	-	-	-	-	
	25	20-	1	1	1	2	-	-	
	30	3.5	0	-	0	-	-	-	
P O L E	Apr 27	5	2	1	0	-	-	-	Injection 20Apr65
	May 7	1	1	2.5	5.5	4	1	-	
	12	0.5	1.5	6+	9-	5	1-	-	
	20	0.5	1-	0.5	-	-	-	-	
	26	0.5	1	0.5	1	1	-	-	
	Jun 1	1	1	1	-	-	-	-	
S U T T O N	Apr 27	1	1	0	-	-	-	-	Injection 20Apr65
	May 7	1	2.5	0	4.5	1	-	-	
	12	6	2-	0.5	1+	0	-	-	
	20	11.5	0.5	0.5	-	-	-	-	
	26	0	1.5	2	0.5	-	-	-	
	Jun 1	1	1	2	-	-	-	-	



TABLE 20  
FLUOROMETRIC READINGS (x-30) OF FLUORESCEIN,  
HUFF SITE, SHEET 1

139

DATE (1965)	HOLE NO.							
	1	2	3	4	5	6	7	8
Jun 10	12.5	18	4	6	5	14	5.5	31
11	12	12.5	3	5	6	5	6	13.5
15	19	18	16	12	3	7	4	5
16	17.5	12	7	8	2.5	5	5	6
17	21	10.5	11.5	15	4	4	5	5.5
22	24.5	14	14.5	12.5	2	3	4.5	3
23	-	14	14.5	15	4	4	7	4
Jul 2	12	14	13.5	8.5	3	6	4.5	5
6	35	25	12	20	3	5	29	31.5
7	40	20	9	15.5	2	3	22	7

TABLE 21  
FLUOROMETRIC READINGS (x-30) OF FLUORESCHEIN,  
HUFF SITE, SHEET 2

DATE (1965)	HOLE NO.									REMARKS
	9	10	11	12	13	14	15	16	17	
Jun 10										
11										
15	4	10.5	8.5	3	12	6	32	16.5	22.5	
16	2.5	9.5	7.5	5	11.5	6	9.5	14.5	10	odd 9 am
17	13.5	7	16	4	6	3.5	100	18	14.5	even 4 pm
22	3.5	6.5	14	3	4	5	9.5	11	20	
23	4.5	42.5	15	7	7	5	9	14	26	
Jul 2	3	7	15	3	4	5	14	15.5	16.5	
6	5	7.5	25	3	5.5	6	9.5	15	19	odd 5 pm
7	4	6	16.5	3	7	6.5	11.5	12	9	even 8 pm 6 am

TABLE 22  
 FLUOROMETRIC READINGS (x-30) OF FLUORESCEIN,  
 HUFF SITE, SHEET 3

DATE (1965)	HOLE NO.							
	1	2	3	4	5	6	7	8
Jul 7	27	17	11	10	3	10	7	10
7	29.5	19	10	17	3.5	6	16	5.5
7	21	45	11	22	5.5	4.5	9	10
7	30	17	15	12	5	3	6	9.5
8	16	12.5	9.5	10	4	5	7.5	7
8	28.5	18	12	8.5	3	5	9	11
Aug 3	27.5	27	11	38	5	5	7	10
10	19	16	8	19	4	4	6	7
24	19	9	12	15	6	5	6	6
31	26	18	18	37	4.5	3	5	3

TABLE 23  
 FLUOROMETRIC READINGS (x-30) OF FLUORESCEIN  
 HUFF SITE, SHEET 4

DATE (1965)	HOLE NO.									REMARKS
	9	10	11	12	13	14	15	16	17	
Jul 7	3	9.5	18	10.5	8	5.5	8	13	14	10 am
7	18.5	20	22	3.5	3.5	7	15	13.5	21	2 pm
7	5	17.5	20	4	5.5	3	14	16	17	6 pm
7	4	12	19.5	4	7	5	14	19	14	8 pm
8	2.5	4	14	3	4	3	9	13	8	6 am
8	5	8	25	4	5	4.5	12	15.5	18.5	even 10 am odd 5 am
Aug 3	6	10	22	5	7	5	26	18	14	
10	4	11	17	3	5	6	9	14.5	16	
24	5	10	26	3	3.5	4	29	10.5	19	
31	5	10	31	6	4.5	4	25	24	-	

TABLE 24  
 FLUOROMETRIC READINGS (x-30) OF PONTACYL,  
 HUFF SITE, SHEET 1

DATE (1965)	HOLE NO.							
	1	2	3	4	5	6	7	8
Jun 10	1	2	1.5	2	1.5	2.5	2	2.5
11	3	3	4.5	0	0.5	0	2	2
15	0	1.5	0	0	1	1	1	1.5
16	1	2	3	3	2	2	0	0.5
17	2.5	2	13	4.5	4	2	2.5	2
22	1.5	2	0.5	1	2	1.5	2	2
23	-	1	0	0.5	0	0	0.5	0
Jul 2	1	2	1	1.5	1.5	0	0.5	1
6	2	2	1	1.5	0.5	1	1.5	15
7	1	2	0	1.5	0	1	1	1

TABLE 25  
 FLUOROMETRIC READINGS (x-30) OF PONTACYL  
 HUFF SITE, SHEET 2

DATE (1965)	HOLE NO.										REMARKS
	9	10	11	12	13	14	15	16	17		
Jun 10											
11											
15	1	4	1.5	0.5	1	0	5	2.5	1		
16	0	1.5	1.5	1.5	2	2.5	0	0.5	0	odd 9 am	
17	37	2	18.5	2.5	2	0	38	9	0	even 4 pm	
22	1	2	1	0	1	1	1	1	1		
23	0	1	1	1	1.5	1	1	1	2		
Jul 2	1	1.5	1	0	0	0.5	0	0.5	0.5		
6	0.5	1	2	1	0.5	1	0.5	0.5	1	odd 5 pm	
7	0	0.5	0.5	2	1	1	8	2	1	even 8 pm 6 am	

TABLE 26  
 FLUOROMETRIC READINGS (x-30) OF PONTACYL,  
 HUFF SITE, SHEET 3

DATE (1965)	HOLE NO.							
	1	2	3	4	5	6	7	8
Jul 7	1	1.5	3	0.5	2	21.5	1	4
7	1	1	0.5	1	0	1	1	0
7	1	1.5	1.5	8	1	1	1.5	1.5
7	1	1	1	1	1.5	1	1.5	1
8	1	1	1.5	1	1	1	1	1
8	1.5	1	2	1	1	1	1	1
Aug 3	2	1	1	2	1	1	1	2.5
10	0.5	1	1	1.5	1	1	1	1
24	1	2	1	2	1.5	1.5	0.5	1
31	1	1	1	1.5	0.5	0.5	0.5	0

TABLE 27  
 FLUOROMETRIC READINGS (x-30) OF PONTACYL,  
 HUFF SITE, SHEET 4

DATE		HOLE NO.									REMARKS
(1965)		9	10	11	12	13	14	15	16	17	
Jul	7	1	1	1	33.5	2	0.5	0	1	0	10 am
	7	2.5	3	1	0	0	1	1	1	1	2 pm
	7	1	2.5	2	1	1	1	1	1	1	6 pm
	7	1.5	12	1	0.5	0.5	0.5	1	1	1	8 pm
	8	1	1.5	1	1	1	1	1	1	2	6 am
	8	0	1	1	1	1	1	1	1	1	even 10 am odd 5 pm
Aug	3	1.5	1.5	2	2	2	2	2.5	2.5	2.5	
	10	1	2.5	1	0.5	0.5	1	1	1	1	
	24	1	0.5	2.5	0	0.5	0.5	4	1	1	
	31	0	0.5	1	0	1	0	1	1	-	



TABLE 28  
FLUOROMETRIC READINGS (x-30) OF FLUORESCIN,  
ROBINSON SITE, SHEET 1

DATE (1965)	HOLE NO.											
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Jun 11	5											
15	26.5											
22												
23	100+	100+	100+	100+	41	81	39	100+	55	53	58	100+
Jul 2	38.5	58	41.5	52	28	29	16	20	27.5	-	19	27
7	45	-	42.5	69.5	22+	21+	16	16	39	10	14.5	32
8	100	-	-	100+	100+	81	100+	100+	100+	100+	100+	100+
Aug 3	-	-	-	-	-	-	-	-	-	-	-	-
4	100+	88	78	52	83	49	27	28	52	29	81	40
10	100+	77.5	46.5	41.5	37	21	21.5	27	27.5	25	29.5	32.5
17	100+	61	32	19.5	44	27.5	27	18+	22	10+	13	18.5
24	100+	41	21.5	23	60	36+	20-	18	16.5	10	13	17-
31	65	45.5	18-	16	28	20-	13+	15.5	14-	8+	9	10.5
Sep 14	82	30.5	12	16	64	17-	14	14	12+	11	11.5	14

TABLE 29  
 FLUOROMETRIC READINGS (x-30) OF FLUORESCIN,  
 ROBINSON SITE, SHEET 2

DATE (1965)	HOLE NO.										REMARKS
	S13	S14	S15	DH1	DH2	DH3	DH4	DH5	DH6	Q	
Jun 11											Injection 10Jun65 12 & 14
15										25	
22											
23	-	100+	100+								
Jul 2	73	29	28	96	91	100+	100+	21.5	100+	25	Pond 100+ Injection 6Jul65 12 & 14
7	-	24	18.5	-	75	75	100+	100+	84	21+	
8	-	100+	100+	-	-	-	-	-	-	22	
Aug 3	-	-	-	-	100+	100+	-	100+	100+	-	
4	100+	57	27	90.5	100+	100+	100+	100+	85	31	
10	100+	50.5	37.5	65	80	78	73	57.5	56	21	
17	72	26+	15-	63	100+	100+	69+	64+	77.5	17.5	Pond 100+
24	56	29	19+	60	74	83	70.5	53	68	34-	Pond 100+
31	45	42	12	82	70	78	71.5	53-	58.5	-	
Sep 14	41	12	12	-	-	-	-	-	-	-	

TABLE 30  
FLUOROMETRIC READINGS (x-30) OF PONTACYL,  
ROBINSON SITE, SHEET 1

DATE (1965)	HOLE NO.											
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Jun 11	0											
15	0											
22												
23	7	8-	5	8.5	2.5	3	1.5	1	3	4	6.5	7
Jul 2	1.5	2	1.5	1	2	1	2	1.5	6.5	-	2-	1.5
7	1	-	2	1.5	2+	2-	2	2	10+	1-	1-	2-
8	1	-	-	0.5	2+	1+	2.5	2	9-	3	2	2+
Aug 3	-	-	-	-	-	-	-	-	-	-	-	-
4	42	4	2.5	0.5	11	3	2	2	12	1	2	2
10	7+	2	1-	2-	4-	1	1+	1+	2	2-	2	2+
17	8+	2+	1	1-	6	3+	4	3.5	4-	1.5	1.5	3-
24	12-	2	2-	1.5	8	3	3	2	2.5	1	1.5	2+
31	3.5	1	1	1	3.5	1	1+	1	2-	1	1-	3-
Sep 14	4	1+	1-	1-	5+	1-	0.5	0	1	0	0	0



TABLE 32  
FLUOROMETRIC READINGS (x-30) OF FLUORESCIEIN  
PLOT 1, LOLO SITE, SHEET 1

DATE	HOLE NO.													
	187	189	192	194	196	199	202	204	212	214	216	217	219	
(1965)														
Jul 16	19	15												
17	11	24												
18	31.5	100	12.5	31.5										
19	17	-	13	26.5										
20	22	-	7.5	45										
23	44.5	22	20	12.5										
24	10	12.5	11	8.5	14	48								
27	-	100+	10	14	12	14								
30	-	18	7.5	37.5	12.5	19								
Aug 6	87.5	45	7	18	13	50								
10	49	28	8	13.5	13	58	23	12						
13							27.5	12	14	10	39	41.5	44	
17							13.5	17	12	22	17	12	13	
20														
22														
27							7	6	8-	55	26.5	38	29+	
31														
Sep 3									8	6				
7														
10							10-	8-	6+	7-	14-	35-	14-	

TABLE 33  
 FLUOROMETRIC READINGS, (x-30) OF FLUORESCIN  
 PLOT 1, LOLO SITE, SHEET 2

DATE (1965)	HOLE NO.										FLUME NO. 1
	222	224	225	227	229	232	234	236	237	239	
Jul 16											
17											
18											
19											
20											7.5
23											13
24											17
27											
30											
Aug 6											57
10											24
13											
17											
20		17.5	100	19-							
22		24	12+	20-		86					
27	10-	10.5	12+	36.5	24	23+	24	60.5	91.5		
31	12	8.5	11	19+	15-	30	36	69	71		
Sep 3				15	12	27+		35-			
7	48	14	6	12	11	18					
10	13-	12.5	4	14	13-	12					

TABLE 34  
 FLUOROMETRIC READINGS (x-30) OF PONTACYL,  
 PLOT 1, LOLO SITE, SHEET 1

DATE	HOLE NO.												
	187	189	192	194	196	199	202	204	212	214	216	217	219
Jul 16	2	2.5											
17	1.5	3											
18	1	1	2	2.5									
19	2		1.5	2									
20	2		0	9									
23	1	0.5	0.5	0.5									
24	1.5	3	0.5	0.5	4	2.5							
27		2	2	2	2.5	2							
30		4.5	3	4	4	5							
Aug 6	15	2	0	2	1	1.5							
10	8.5	2.5	2.5	3	4	9	2	2					
13							3.5	2	2	2	3	3	4.5
17							4	2.5	4	4	3	3.5	4
20													
22													
27							0.5	0.5	1-	0.5	0	0	+
31													
Sep 3							0.5		1-				
7													
10							1+	1	1-	1	1	2.5	1.5

TABLE 35  
 FLUOROMETRIC READINGS (x-30) OF PONTACYL,  
 PLOT 1, LOLO SITE, SHEET 2

DATE	HOLE NO.										FLUME NO. 1
(1965)	222	224	225	227	229	232	234	236	237	239	
Jul 16											
17											
18											
19											
20											
23											1.5
24											2.5
27											2
30											
Aug 6											0.5
10											4
13											
17											
20		1	18-	2							
22		4.5	4-	1		14.5					
27	0	0	0	0+	0	10+	0.5	0.5	1+		
31	1-	1-	1	1	1-	1	1-	2+	3+		
Sep 3				1-	2	1		3+			
7	2.5	2	0.5	1	1	1					
10	1+	1	1.5	1+	3-	1					



TABLE 36

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TRITIUM CONCENTRATIONS (in Tritium Units),  
PLOT 1, LOLO SITE

HOLE NO.	DATE (1965)									
	18Jul	20Jul	23Jul	30Jul	6Aug	20Aug	24Aug	27Aug	31Aug	10Sep
125		3060	1530							
127			918	2142						
129	4284	1836	1224							
134		3366	1836	2142	2754					
139					2448					
142								1836		1530
144								1530		
145										<612
147						6426		<612		<612
149						3060		<612		1530
152								<612		
154										<612
155										<612
156								<612		
165							2448	<612	<612	<612
166						1836	5508	<612	1530	
167						<612		<612	<612	
168									2448	<612
169							1224	<612	2448	<612
172							1836	2142		
174						1836	3978	<612	2142	<612
176						6732		<612		<612
179						<612		<612	<612	
x(250)								1530	2142	

TABLE 37  
 FLUOROMETRIC READINGS (x-30) OF FLUORESCIN,  
 PLOT 2, LOLO SITE, SHEET 1

DATE (1965)	HOLE NO.														
	124	125	126	127	129	132	134	136	137	139	142	144	145	147	149
Jul 16		69	35	44	100+										
17		75	30	22	100+										
18	49	100+			100+	66	38								
19	38	100+			100+	46	29								
20	35	87			76	27	30								
23	35.5			35	86	33.5	100+								
24	38.5	31		30	84	22	54.5	34	22						
27	20	29		18	100+		18	22							
30	47			38.5	51		21	21.5	100+	37.5					
Aug 6	40			35	67		19	17	100+	100+	100+	100+	33		
10	16			43	85	22	9	13	100+	82	64	20	20		
13											100+		25	23	
17											52		24	100+	15
20															
22															
27											19	100+	75	83	18
31															
Sep 3															
7															
10											22-		25	61	8.5

TABLE 38  
FLUOROMETRIC READINGS (x-30) OF FLUORESCEN  
PLOT 2, LOLO SITE, SHEET 2

DATE	152	154	155	156	157	165	166	167	168	169	172	174	176	179	x(250)	FL2
(1965)																
Jul 16																21
17																29
18																28.5
19																21
20																19.5
23																
24																
27																
30																
Aug 6																
10																
13	28	43	8.5	92												
17	20	30	45.5	100+	14.5											
20						14-	39-	14-	16.5	37	15	35	66.5	31	67+	
22						25	41	9	28	58.5	30	39	82+	43		
27	10	8.5	50	56		7.5	90	8	15	50	36-	59+	64+	45.5	79.5	
31						36.5	87.5	18.5	24	58-	22	44	65	29	57	
Sep 3	11	24.5	10			9-	27	11	27	37-	77	33	100+	100+		
7	7-	6+	19	45+		9	66	16	17	50	85	22	35	39	17	
10					6+	6+		13.5	28	44.5	32	34+	64	24	44-	

TABLE 39  
 FLUOROMETRIC READINGS (x-30) OF PONTACYL,  
 PLOT 2, LOLO SITE, SHEET 1

DATE	HOLE NO.															
(1965)	124	125	126	127	129	132	134	136	137	139	142	144	145	147	149	
Jul 16		5	1.5	2.5	27											
17		8	2.5	13	37											
18	1	20			44	2.5	3.5									
19	1.5	16			32.5	4	1.5									
20	3	15			11	2	1.5									
23	0.5			0.5	1.5	0	6									
24	0.5	0		0	1.5	1.5	2.5	1.5	1.5							
27	2	2		3.5	43		1	1.5								
30	6			4	5		5	4	68	4.5						
Aug 6	3			2	6		4	3	32	10.5	20	56	4			
10	3			4.5	9	2.5	2.5	2.5	40	7	6.5	4.5	4			
13											11+		15		3	
17											3		1.5	2.5	2	
20																
22																
27											0.5	7	1	1+	0.5	
31																
Sep 3																
7																
10																

TABLE 40  
FLUOROMETRIC READINGS (x-30) OF PONTACYL,  
PLOT 2, LOLO SITE, SHEET 2

DATE	HOLE NO.																FL2
(1965)	152	154	155	156	157	165	166	167	168	169	172	174	176	179	x(250)	FL2	
Jul 16																2	
17																2.5	
18																2	
19																0.5	
20																1	
23																	
24																	
27																	
30																	
Aug 6																	
10																	
13	3.5	15	6	4.5													
17	2	6	4	5	2.5												
20						1+	1+	1+	6	1+	1	3	3+	3+	5		
22						2+	2	1	1+	1+	2	1	1-	1+			
27	0+	0+	3.5	1-		1-	1	1	1	0.5	1	1-	1-	1	5-		
31						1	1	1-	3	1	1	1-	1	1	1		
Sep 3	1	1	4-			1	1	1-	1-	0.5	15	1-	6.5	4.5	17.5		
7	4-	1+	1+	2.5		1	1	2	1	0.5	13	0.5	0	0.5	1.5		
10					1	1-	1	1	5	1	2.5	1	1-	1	4		

TABLE 41  
TRITIUM CONCENTRATIONS (in Tritium Units),  
PLOT 2, LOLO SITE

HOLE NO.	DATE (1965)					
	13Aug	20Aug	27Aug	31Aug	3Sep	10Sep
204	1224					
212	1530		612			612
214						1530
216			1530			1836
219						612
222				2745		
224		2745	2745	918		
225		4284	3978	2142		
227		1530 918	1530 1530	1836	2142	
232			1836	612		
234			1530			