AN EXAMINATION OF THE SPATIAL VARIATION OF SURFICIAL SEDIMENT CHARACTERISTICS IN THE HOWISON'S POORT RESERVOIR

by

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CHAPTER 1

INTRODUCTION

1.1 Preamble.

Lakes, estuaries and man-made water impoundments can be considered as intervening basins which provide for the temporary storage both of sediment and of water. Because of the potential energy of soil in elevated positions and because of the kinetic energy of water flowing under the influence of gravity, eroded material is eventually transported to the lowest possible level, i.e. the ocean deeps, or some intervening basin. This denudation process may be compared with Newton's second law of thermodynamics which states that each system tends to move in the direction of lowest energy. Sedimentation in intervening basins may be seen as part of the natural process of landscape evolution. The rates at which sedimentation occurs may be strongly influenced by the activities of man.

Reservoir sedimentation is a phenomenon of concern to various technical and scientific fields of research, especially in present times in South Africa where a large number of reservoirs have been constructed. Up to the 31st March 1976, over R1 140 000 000 had been spent on government water projects in South Africa (van der Spuy, 1977). It is therefore not surprising that the sedimentation of reservoirs with consequent costly loss of storage capacity has been a subject of concern in recent years. In addition to the reduction in water volumes immediately available for domestic, agricultural or industrial use, sedimentation may result in a reduction of flood control storage and of carry over storage capacity for drought periods. A separate but no less important aspect of sedimentation is that of water quality. As a direct result of sedimentation it has been estimated that 64% of all United States reservoirs have useful life spans of less than 100 years (Witzig, 1943). In South Africa the problem is particularly acute because of the generally unfavourable combinations of topography, climate and geology in areas where major dams are situated. Erosion rates are particularly high in the Orange Free State and in parts of the Cape because of exposure to the soft strata of the Karroo Supergroup and the low vegetal cover resulting from the semi-arid climate. In the Transkei, Natal and Eastern Transvaal often poor land management has caused increased rates of erosion. The steep mountain slopes and the high incidence of fire in the South Western Cape results in increased erosion rates (Menne and Kriel, 1959).

The problem of reservoir sedimentation has received attention from researchers both in South Africa and abroad. Three broad fields of reservoir sedimentation research may be distinguished ; a) the production of sediment within reservoir tributary catchments, b) the transportation of sediment to reservoirs by tributary streams and c) the deposition of that sediment within the reservoir. Figure 1 shows schematically the links between these fields of research with special reference to some of the more important aspects of these categories which have been studied by research workers in South Africa. The studies listed under groups A and B in figure 1 have application in the planning stage of reservoir construction. The work listed in these two categories enable an estimation of the trap efficiency and the predicted lifespan of reservoirs to be made prior to its construction. Group C refers to research done on the sediments occurring within reservoirs. The two major categories of research in group C are those by Roosenboom (1974) and the Department of Water Affairs (1978, pers. comm.). Roosenboom described the mathematical relationships of the hydraulics of reservoir sediment movement. The Department of Water Affairs is responsible for an ongoing survey

FIELDS OF RESEARCH ON RESERVOIR SEDIMENTATION IN SOUTH AFRICA.

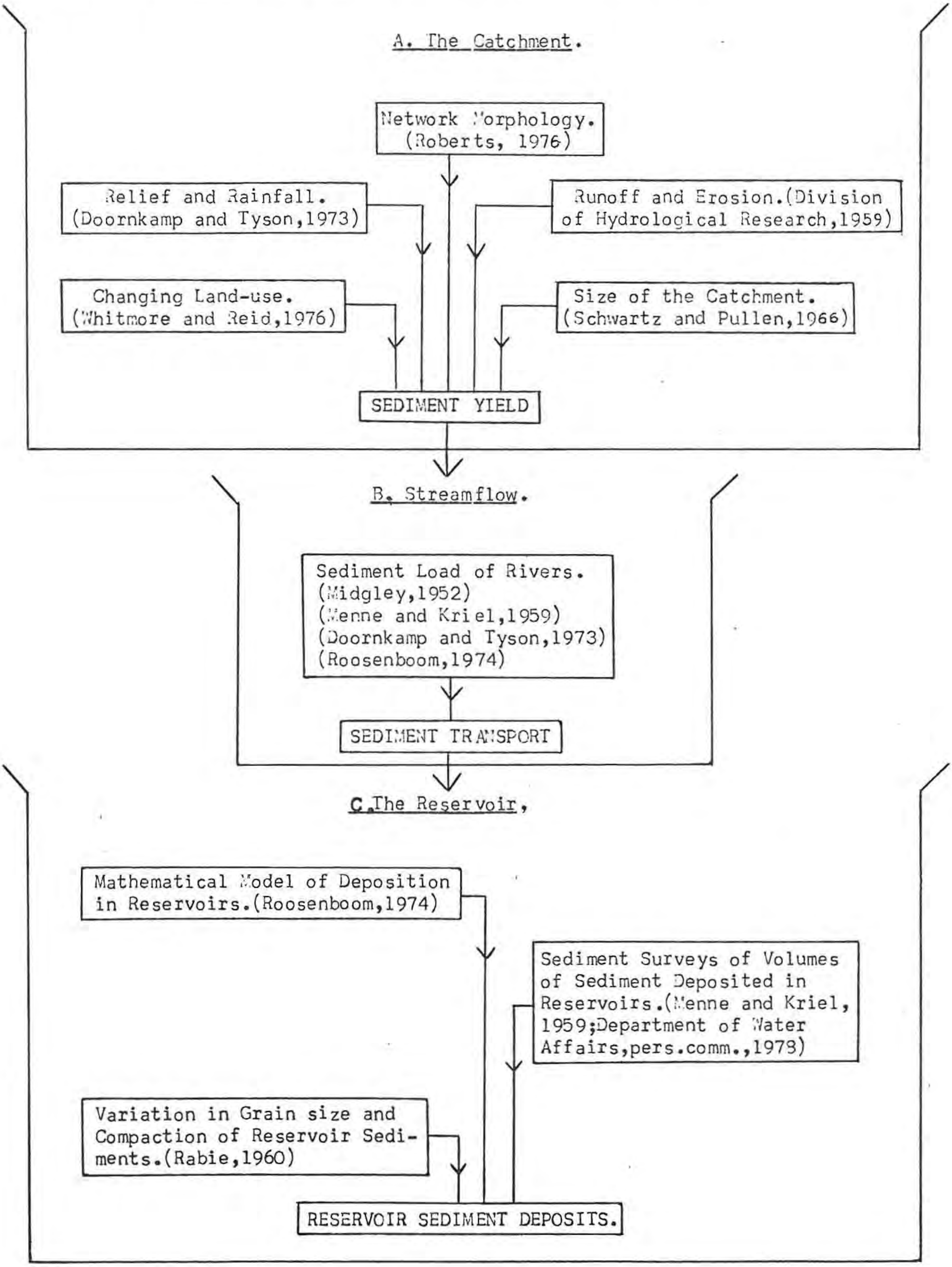


Figure 1.

project whereby changes in sediment volume in the major South African reservoirs is monitored. Another research worker in this field was Rabie (1960) who described variations in grain size distribution and compaction of sediments in the van Ryneveld's Pass and Grass Ridge dams.

Although a number of studies have been published on the input of sediment into reservoirs and on the rates of accumulation of sediment in reservoirs; a comprehensive survey of the literature shows that Roosenboom (1974) and Rabie (1960) are the only two authors who have studied distributional patterns of sediment within reservoirs. Personal communication with various officials of the Department of Water Affairs in Pretoria confirms that there is a need for empirical investigations of the distribution of sediments within reservoirs to compliment the few theoretical studies which have been undertaken to date. The starting point for this thesis on the sediments of the Howison's Poort reservoir is the existing body of theory on reservoir sedimentation, and in a wider context a consideration of the fundamental physical concepts of sedimentation processes. The specific aims of the thesis are outlined in chapter 3, but in general terms the study contributes a spatial component to the existing knowledge of the temporal and volumetric aspects of reservoir sedimentation which have been the major concern of most of the existing published research.

1.2 The Study Area.

To facilitate a comparison of results of this study with possible future studies elsewhere, a summary of the principal reservoir and catchment attributes is provided. The area chosen for the present study was the Howison's Poort reservoir. Figure 2 shows the location of the study area, the boundaries of the contributing catchment and the topography of the area.

LOCATION OF THE STUDY AREA; SHOWING RELIEF, CATCHMENT BOUNDARY AND TRIBUTARY STREAMS

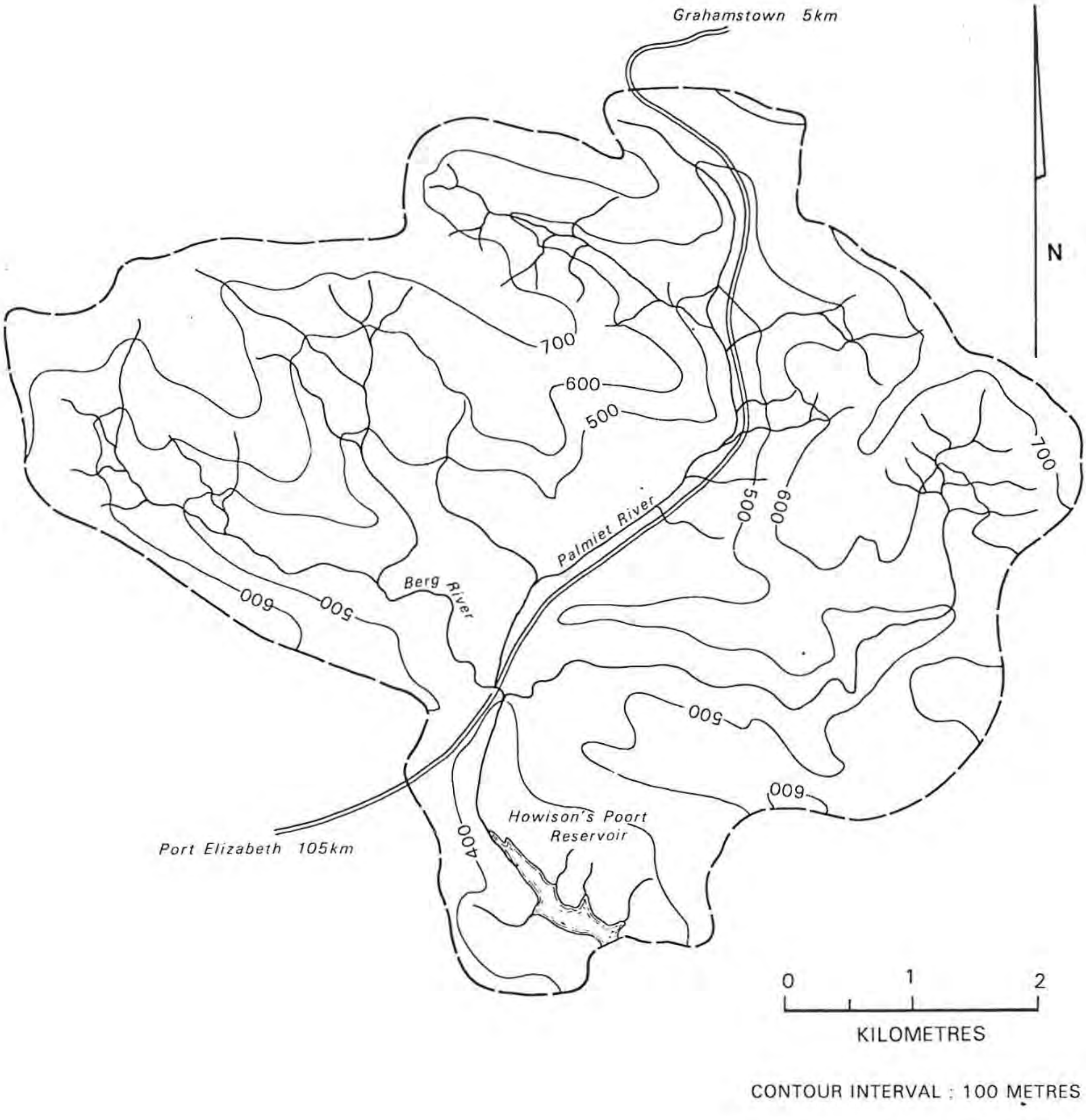


Figure 2.

The Howison's Poort reservoir is situated on the Palmiet river approximately 15 kilometres south of Grahamstown. The concrete dam wall was constructed in 1940 and the reservoir served as a source of water supply for Grahamstown. The Grahamstown water supply is at present obtained from the Howison's Poort reservoir and the more recently constructed Settler's reservoir (1967) which is situated at the confluence of the Kariega and Palmiet rivers approximately 1 kilometre downstream from the Howison's Poort reservoir. The Howison's Poort reservoir was surveyed by the Grahamstown Municipality in 1953 and was estimated to have a capacity of 900, 1 x 10^3 M^3. The reservoir measures approximately 800 metres along its long axis and tapers from approximately 100 metres at the dam wall to less than 10 metres at the main inlet. The deepest point in the reservoir is 14,90 metres.

The reservoir is fed by the Palmiet river, a tributary of the Kariega river, and four minor, unnamed streams. The Palmiet river has a catchment area of 34 square kilometres, the minor streams have a total catchment area of 1,8 square kilometres and there is a further 0,6 square kilometres contributing directly to the reservoir. The altitude of the catchment area varies from 770 metres above sea level in the north to 305 metres above sea level at the dam wall. The catchment relief has a hypsometric integral of 0,53 (figure 3).

80% of the lithological outcrop of the catchment is comprised of Witteberg sandstones and 20% of Bokkeveld shales (Lock, 1974). Martin and Noel (1960) classified the soils in the area as the light, sandy soils derived from the Witteberg sandstones and the heavier loams derived from the Bokkeveld shales. The catchment is covered by 30% woodland (Cowan, 1977) and the remaining area consists of scrubland (Jacot-Guillarmod, 1974). The vegetation type falls into

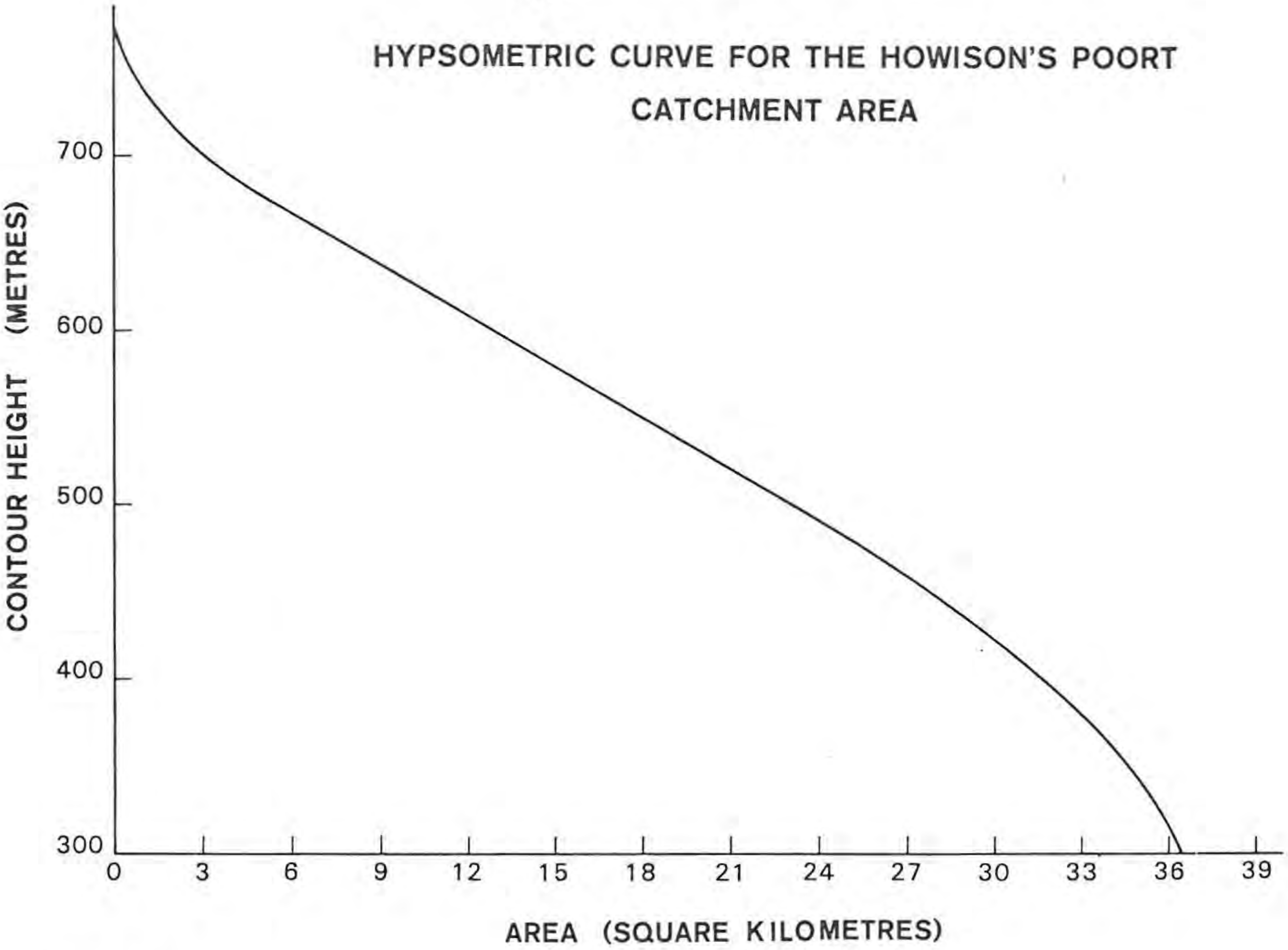


Figure 3.

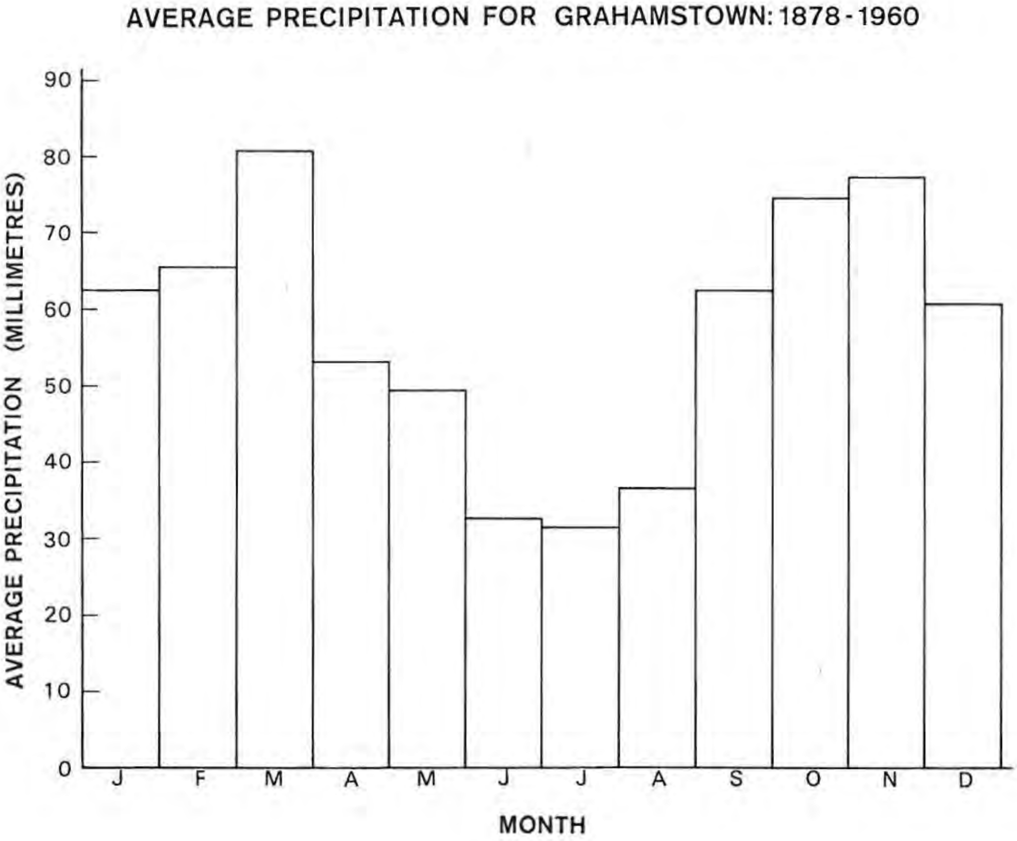


Figure 4.

Acock's (1953) False Macchia veld type with elements of Eastern Province thornveld and valley bushveld. Jacot Guillarmod (1974) and Cowan (1977) observed that there has been gross infestation by weed species such as pines (pinus pinaster), eucalypts (ecalytus), hakea and Australian acacia (acacia longifolia, acacia mearnsii). Plate 1 provides a general impression of the scrubland-type vegetation surrounding the Howison's Poort reservoir.

The area falls into Köppen's Cf climatic group; i.e. temperate, warm and humid with rain in all seasons (Department of Planning, 1966). Figure 4 shows the mean annual rainfall for Grahamstown. The Grahamstown rainfall figures are used because there are no long term records available for the catchment and those for Grahamstown are the nearest alternative source. The mean annual rainfall recorded for the period between 1878 and 1960 is 687,8 millimetres. The mean annual runoff according to Midgley and Pitman (1969) is 407 255 cubic metres per year.

There were several reasons for choosing the Howison's Poort reservoir for the present study,

a) it is of a feasible size as far as time, cost and available equipment is concerned;
b) the travel distance from the university to the site for purposes of field data collection was negligible;
c) the catchment attributes have already been well documented by other workers (e.g. Jacot Guillarmod, 1974; Lock, 1974 and Cowan, 1977);
d) The Grahamstown Municipality provided financial assistance and full co-operation for the areal survey of the reservoir;
e) the reservoir is maintained at a fairly constant level (fluctuations cause complications in sedimentation patterns (Eakin, 1936)).

The following chapter discusses the theoretical background to the thesis. Chapters 3 and 4 present the aims and hypotheses of the study which are based on the theoretical background. In chapter 5 the collection of the data necessary for the testing of the hypotheses is discussed. The statistical results of hypothesis testing are presented in chapter 6 in the context of the theory outlined in chapter 2. The final chapter discusses the results obtained from the testing of the hypotheses with respect to their sedimentological significance and presents a generalized response model of the spatial distribution of surficial sediment characteristics of reservoirs. At the end of the thesis appendices A, B, C and D discuss the methods of analysis used in the study in full detail because of their relevance to possible future studies in the same field.

Plate 1 : VIEW FROM THE NATIONAL ROAD TO THE HOWISON'S POORT RESERVOIR SHOWING THE SCRUBLAND-TYPE VEGETATION.

CHAPTER 2

THEORETICAL BACKGROUND TO STUDY

This chapter is divided into four sections. The first section (2.1) discusses the general principles of sediment deposition in reservoirs and examines the processes affecting the spatial distribution of sediment within fresh water impoundments. The following section (2.2) considers the distribution of biogenic matter in reservoirs. In section 2.3 the use of grain size parameters as tools for the interpretation of sedimentary environments is discussed with special reference to their usefulness in the present study. The general framework of the thesis is concerned with the relationship between depositional and transporting processes and their sedimentary response; for this reason, consideration of process-response models of sedimentary environments is provided in the final section (2.4). The study aims and the hypotheses, which are based on the theoretical background are presented in chapters 3 and 4.

2.1 Reservoir Sedimentation

2.1.1. The deposition of inorganic sediment in reservoirs

The processes of transport and of deposition of sediment operate under the same physical laws. "The two fundamental aspects of sediment transportation are the settling velocity of the particles, and the laws of fluid motion." (Krumbein and Sloss, 1964, p. 196).

(a) Settling velocity of particles

The most important characteristics of sediment particles which affect the rate of settling are size, shape and density. The relationship between grain size and settling velocity of particles is usually idealized by Stokes' Law and the Impact Law (Griffiths, 1967). If the particle is less than 0,1 mm in diameter, it will tend to settle out at rates defined by Stokes' Law :

$$V = Cd^2 \quad \text{......} \quad (1)$$

where: V = settling velocity

d = particle diameter

C = a constant related to relative densities of fluid and particle, acceleration due to gravity and the viscosity of the fluid (Gary, McAfee and Wolf, 1973).

Particles which are too large to be affected in their settling by fluid viscosity tend to settle out at rates described by the Impact Law (developed by Newton in 1687):

$$V = C\sqrt{d} \quad \text{......} \quad (2)$$

where: V = settling velocity

d = particle diameter

C = constant (as above in (1)).

Krumbein and Sloss (1964) compared the curves of settling rate vs particle size diameter that should in theory be produced by application of the two laws with the actual curve produced by measurement from experimental data (figure 5). They showed that Stokes' Law plots as a concave parabola and the Impact Law as a convex paraboloid. The observed data for small grains follow the Impact Law. In a transitional zone, the experimental data agrees with an average between the two laws.

Particles greater than those accounted for by the Impact Law settle under the influence of gravity only, other factors are of little importance (Twenhofel, 1950). Colloidal particles (with a diameter of 1-10 μm) are maintained in suspension because of complex exchange mechanisms related to electrical activity between the particles and the water and only settle out of suspension when flocculation takes

COMPARISON OF EXPERIMENTAL DATA ON SETTLING VELOCITY WITH STOKES' LAW AND THE IMPACT LAW

(Data adapted from Rubey(1933) in Krumbein and Sloss, 1964, p.198)

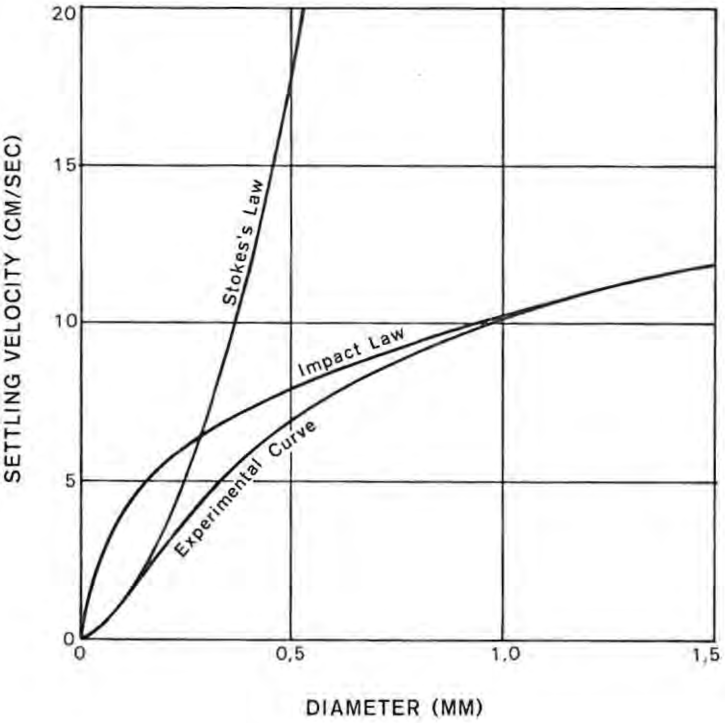


Figure 5.

place and as an aggradated group of particles the sediments are able to overcome fluid viscosity.

The findings of Lane in 1938 (Twenhofel, 1950) appear to be confirmed from the research by Krumbein and Sloss (1964) that the settling of cohesionless particles greater than 0,3 mm in diameter are shown to vary as the square root of the diameter and those with diameters below **0,1 mm** in diameter vary with the square of the diameter. The relationship between particle settling velocities and grain size is extremely useful in sedimentology. Where current conditions into a lake (for example) remain constant, the finer particles will be carried much greater distances than the coarser particles and the resultant feature will be a regular gradation of particle size away from the source (Krumbein and Sloss, 1964).

(b) Fluid Flow

Stokes' Law and the Impact Law assume a motionless body of water. In natural conditions this is rarely the case. The various states of fluid flow in sedimentary environments complicate the patterns mentioned above to a lesser or greater extent. Two types of fluid flow have been distinguished; laminar flow and turbulent flow. A differentiation between these two flow types is best illustrated by the Reynolds' experiment. Reynolds designed an experiment in which a narrow thread of dye was released at the centre of a long straight tube filled with steadily flowing water (figure 6). Laminar flow is characteristic of flow conditions with flow velocities below a critical threshold value where the dye thread remains straight and of practically constant width. Laminar flow is characterized by linear streamlines. When the flow velocity exceeds the critical threshold value, the thread becomes distorted; the distortion changing from instant to instant, i.e. a turbulent flow (Allen, 1970).

REYNOLDS' EXPERIMENT ON LAMINAR AND TURBULENT FLOW (Allen, 1970, p.33)

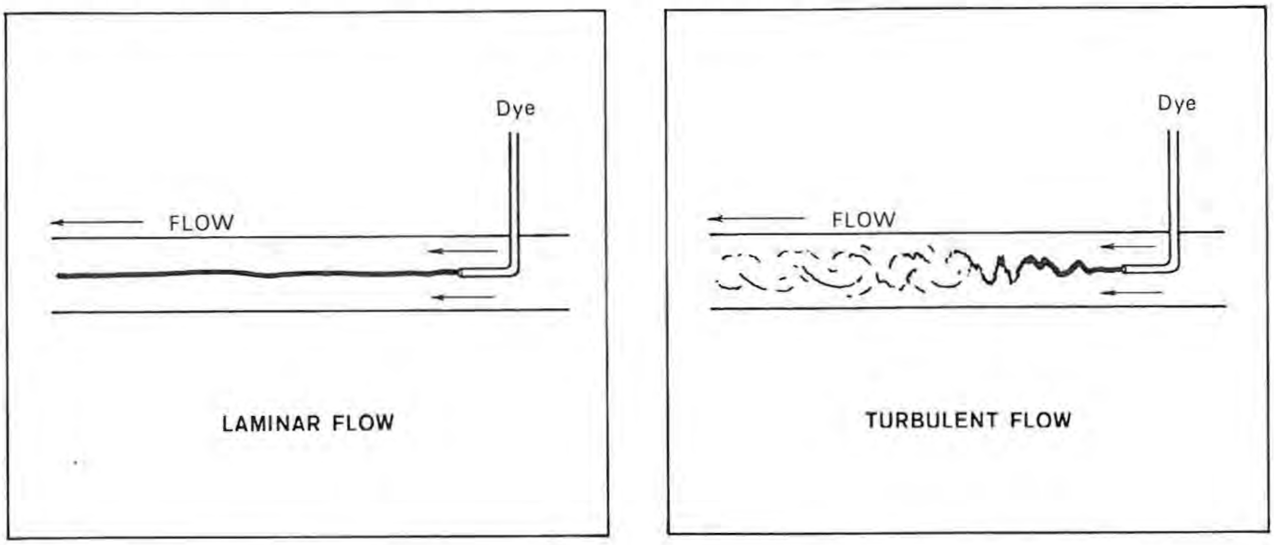


Figure 6.

Turbulence is measured on a scale of dimensionless Reynolds numbers (Re); Re less than 500 denotes laminar flow and Re values of greater than 2000 denote turbulent flow. The flow of water in lakes is almost always greater than Re 500 (Mortimer, 1974). Particles in the size range which settle under conditions of settling defined by Stokes' Law can be carried for long distances by even the slightest amount of turbulence (Twenhofel, 1950). Sediments in reservoirs and lakes within the Stokes' settling velocity size range may therefore be maintained in suspension for long periods of time.

(c) Transport of particles

Once movement of particles has been initiated, the distance these particles are transported is largely a function of their settling velocity which in turn can be affected by turbulent flow. For example, although small sand grains require less initial energy to be brought into suspension than cohesive clay sediments, the sand grains tend to settle more rapidly whereas the clays remain in suspension because of lower settling velocities (Krumbein and Sloss, 1964). These hydrodynamic relations were formalized by Hjulstrom, (1939) (figure 7), but have been the subject of many research workers both before and since, for example, Gilbert (1914), Wentworth (1933), Nevin (1946), Allen (1970), and Yang (1973).

(d) Fluid flow and sediment deposition in Reservoirs

It has been shown that sediment deposition is a function of the settling velocity of the constituent sediment particles and the state of flow of the fluid. The state of flow of the fluid is, in turn, a function of the velocity of flow of that fluid. When a fluid flows from one point to another, a conservation law is in operation (assuming a constant fluid density throughout the region of flow). This law can be illustrated by considering the constant

HJULSTROM'S DIAGRAM OF THE RELATIONSHIP BETWEEN
EROSION, TRANSPORTATION AND DEPOSITION OF SEDIMENTARY PARTICLES
(Krumbein and Sloss, 1964, p.203)

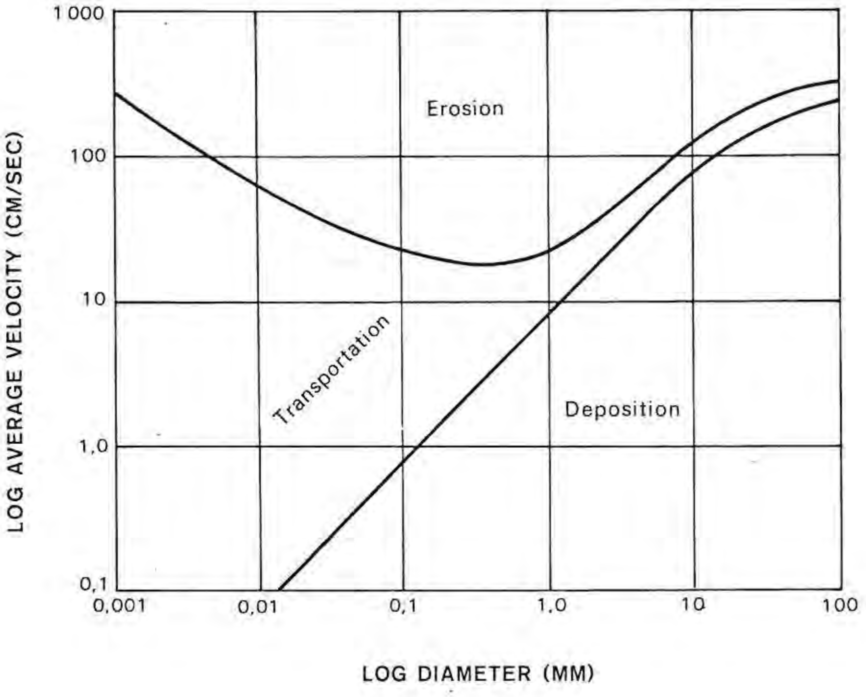
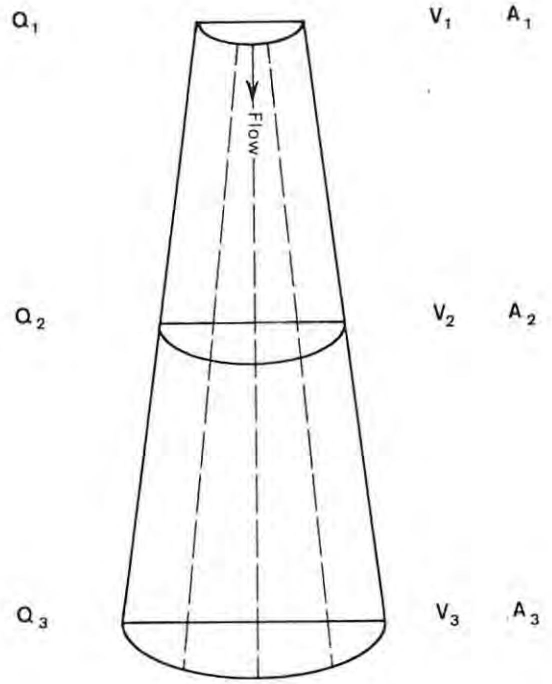


Figure 7.

volume of discharge of water, Q (m^3/sec), through a stream channel of varying cross-sectional area, A(m^2), and varying average velocity V(m/sec). Then $Q = V. A. = V_2 A_2 = V_3 A_3$ (Morisawa, 1968) (Figure 8).

If the same stream channel were to empty into a hypothetical reservoir of increasing cross-sectional area, the same relationship would hold; i.e. with increasing cross-sectional area, the mean velocity of flow will decrease. With decreasing velocity of flow there will be a decreasing intensity of turbulence, until,

THE RELATIONSHIP BETWEEN FLOW VELOCITY AND CROSS-SECTIONAL AREA UNDER CONDITIONS OF CONSTANT DISCHARGE



$(Q_1 = Q_2 = Q_3, \quad A_3 > A_2 > A_1 \therefore V_3 < V_2 < V_1)$

Figure 8.

hypothetically, laminar state of fluid motion is reached.

The effect of turbulent flow on the settling particles will, therefore, decrease from the point of entry of the stream into the reservoir to the reservoir wall. Particles able to settle out in the upper reaches of the reservoir will be those which are large enough to overcome both the viscosity and the turbulent motion of the transporting agent. Assuming constant viscosity of water from the point of entry to the reservoir wall, settling out of particles will be primarily influenced by turbulence until only size ranges which obey Stokes' Law remain in suspension. Velocity of flow becomes less with distance from the point of entry of the stream and the resistance offered by the water to particle settling increases with decreasing particle sizes (Twenhofel, 1950). The only forces retaining the particles in suspension are therefore the resistance of water to settling, the turbulence and the electrical activity between water and particles. In reservoirs exhibiting transitional decrease of hydrodynamic activity away from input areas there will be an initial rapid decrease in mean sediment grain size until the lower limit of grain sizes settling under conditions as described by the Impact Law is reached (1,0 mm); followed by a less rapid decrease in grain size until the upper limit of Stokes' Law conditions is reached (0,1 mm); followed by a levelling out as particles settling under Stokes' Law are gradually deposited. Empirical support for such a transitional sequence of sedimentation is found in Lewis (1936), Brown (1949), Menne and Kriel (1959), Rabie (1960) and Borland (1971).

The pattern described above is, however, influenced to varying degrees by a number of auxilliary processes at work within the reservoir environment. These "sub-environments" will be discussed in the section that follows.

2.1.2 The distribution of inorganic sediments in reservoirs

The preceding section examined the factors affecting the deposition of sediment in reservoirs and showed that there is a general trend for sediments to decrease in size with distance from their point of entry to the reservoir. Although this general pattern has been documented in reservoirs, within this broad pattern two separate groups of sediment are discernable, namely deltaic and density current deposits. The division of reservoir sediments into these groups may be still further complicated by water circulation patterns initiated by wind and/or temperature fluctuations and by shallow water turbulence produced near the reservoir banks. The principle processes which operate to produce distinctive deltaic and density current sedimentation are considered in detail in the following sections (a & b) and consideration of other effects such as wind and temperature is given in section c.

(a) Deltaic deposits

Deltas are characteristically composed of the relatively coarse grained sediments representing the largest grain sizes of the suspended and bed load of the stream feeding the reservoir. The characteristics and presence of the delta in a reservoir is thus largely dependent on the proportion of relatively coarse grained sediment in the streamborne load (Eakin, 1936). The shape of the delta is a function of the ratio between the mean grain size within the load and the velocity of stream flow. "... a coarse-grained sediment transported by a current of given strength may yield a foreset with an angular basal contact, whereas fine grained sediment transported under comparable conditions may yield a strongly tangenital contact." (Jopling, 1965, p. 773). Figure 9 represents an idealized diagram of a typical reservoir delta.

PROFILE OF A TYPICAL RESERVOIR DELTA (Borland, 1971, p.29-3)

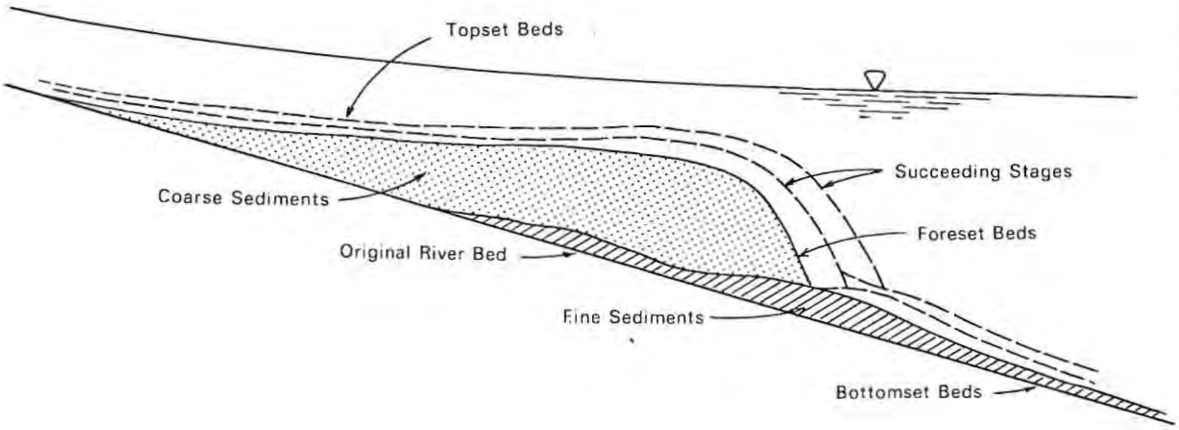


Figure 9.

Deltas are formed by the sedimentation process known as aggradation (Borland, 1971). The sediment is sorted as it is deposited. The finer material is carried out into the reservoir and spread over the bottom (bottomset beds). This portion of the delta is made up of the coarser portion of the finest sediment in the suspended load of the stream (Stevens, 1934). The coarser, bed load material is also sorted and is deposited in a fan shape on top of the bottomset beds. These deposits are known as foreset beds

(Stevens, 1934). Topset beds constitute subsequent suspended loads of the stream which are deposited on top of the fairly level surface of the foreset beds (Stevens, 1934). These typically deltaic characteristics are often destroyed by seasonal variations in reservoir level, variability of stream regimen and variability of materials transported

The sedimentary characteristics of deltas include the typical profile, the relatively large mean grain size of sediment and the good sorting values of the sediments.

(b) Density Current Deposits

The second major group of sediments in reservoirs are those transported to the point of deposition by density currents. Water flowing into a reservoir with a high sediment load has a higher density than that of the water stored in the reservoir. The result is that the denser water flowing into the reservoir flows under the lighter water in the reservoir (Allen, 1970). Howard defines a density current as being "... the movement, without loss of identity by turbulent mining of the boundary surfaces, of a stream of fluid, under, through, or over a fluid, with which it is miscible and the density of which varies from that of the current, the density difference being a function of the difference in temperature, salt content and/or silt content of the two fluids." (Howard, 1953, in Roosenboom, 1974, p. f12).

The nature and extent of density currents depends largely on the amounts of sediment entering the reservoir, the proportion of fine sediment in the inflowing stream and the slope and depth of the reservoir (Roosenboom, 1974). Density currents tend to follow the thalweg of the reservoir. Where the thalweg is well defined, these currents might even be confined to the thalweg. Where there is an ill defined thalweg, density flow will tend to spill over the old stream channel (Witzig, 1943; Menne and Kriel, 1959).

Ludlum (1974) estimated that approximetely 50% of the sediments deposited in Fayettville Green Lake (New York) can be accounted for by density currents.

The physical state of the suspended sediment in density flows is termed "autosuspension" due to the fact that density currents are sediment transporting systems that owe their existence to the sediment rather than the fluid (Blatt, Middleton and Murray, 1972). The transporting power of the density current depends on its density (or viscosity) and the velocity of flow. As the density, or viscosity of the body increases, the lower is the velocity required to transport a given size, " ... also, as these properties increase, the less effective is the medium as a sorting agent" (Pettijohn, 1957, p. 590). Trask (1950), Visher (1969) and Kukal (1971) have also noted the fact that density currents tend to deposit poorly sorted material.

The areal extent of sediments deposited by density currents has long been the subject of controversy amongst research workers. Faris (1933) believed that no suspended silt was carried through reservoirs until all of the clear water has been discharged. Faris' belief has since been disputed by numerous workers. One of the earliest observations of the extent of density currents was made by geologists in Lake Geneva (Switzerland) where the Rhone River flows at least 10 km to a depth of over 330 m. as a density current (Blatt, Middleton and Murray, 1972). In Lake Mead (U.S.A.) engineers observed that fine clay and silt was transported to the lower parts of the reservoir by underflows with velocities reaching 30 cm/sec. (Blatt, Middleton and Murray, 1972). Witzig (1946) observed density currents flowing as far as the outlets of certain reservoirs. Linsley and Franzini (1972) state that reservoir trap efficiency may be decreased by up to 10 percent if it is possible to vent density currents through sluiceways.

Direct observation and/or measurement of density currents is extremely difficult, if not impossible so that many details of interpretation remain controversial (Blatt, Middleton and Murray, 1972).

Sedimentary characteristics of density current deposits are their relatively fine mean grain size and their relatively poor sorting value.

(c) The influence of wind and temperature on the patterns of circulation in reservoirs

Wind and temperature exert influence on water circulation patterns within lakes and reservoirs. These patterns of circulation result in turbulence and prevent the settling of finer particles in the reservoir. Wind and thermally generated turbulence is especially active in the uppermost layers of the water body. Solar heating of the upper water layers causes the warmer water (epilimnion) to "float" on top of the lower relatively cooler water (hypolimnion). This thermal stratification of water leads to the formation of a marked thermocline which acts as a natural barrier between the two layers of water (Collingwood and Davis, 1973).

Turbulence in the epilimnion is initiated and controlled by two mechansisms:

(i) by wind motion at the air/water interface which extends downwards into the epilimnion,

(ii) by heat exchange across the water/air interface which results in turbulence due to the positive or negative flux of temperature (heat molecules) between the two bodies (Mortimer, 1974).

In mechanism (ii), the net flux of heat varies according to the difference between atmospheric and water body temperature. The flux can be either positive (downward), or negative (upward) depending on the season. The consequence of the flux is to create buoyancy gradients in the water column. Mechanism (i) is predominantly positive (Mortimer, 1974).

Mechanisms (i) and (ii) oppose each other in their influence on the generation of turbulence during a phase where water temperatures are increasing; i.e. the momentum flux creates turbulence but the heat flux and resultant buoyancy flux suppresses it. During a cooling phase, mechanism (ii) results in a progressive destruction of the thermocline and combined with mechanism (i) eventually creates a condition of complete basin mixing (Mortimer, 1974) (Figure 10).

STAGES IN THERMOCLINE DESTRUCTION (Mortimer, 1974)

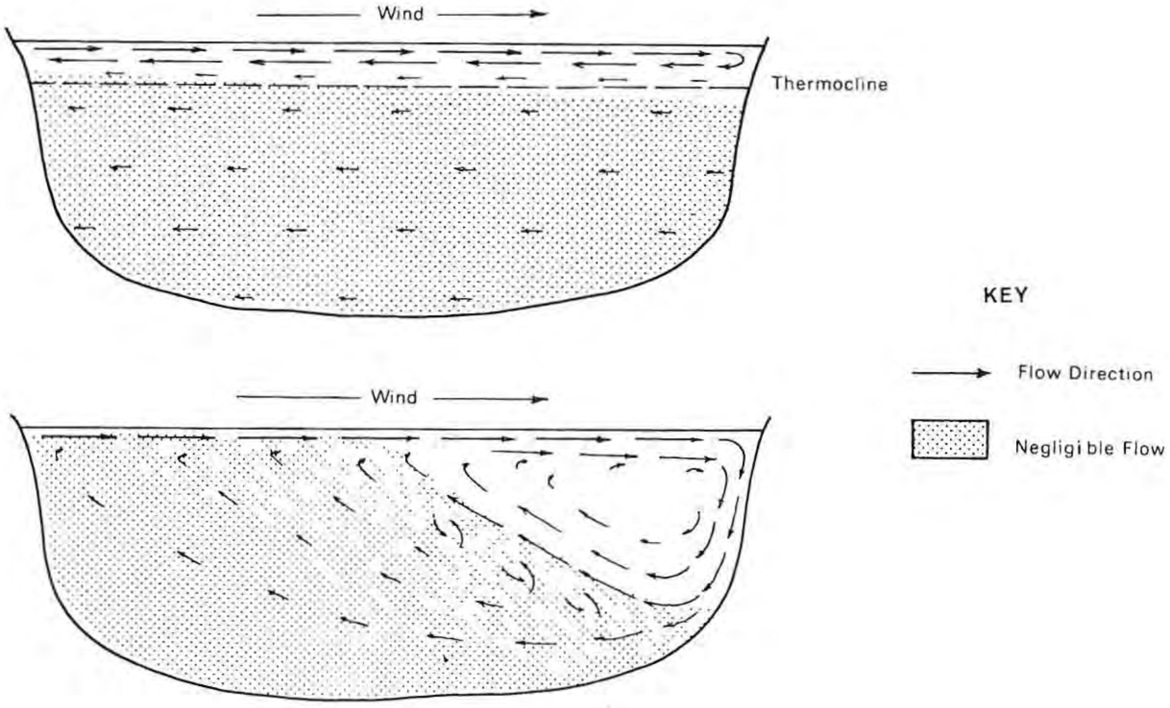


Figure 10

Limnological studies on reservoirs in South Africa have shown that definite thermoclines begin to develop in October (spring warming up) with definite stratification during December. During the winter months there is only a heat build-up at very top layers and the reservoirs have virtually isothermal conditions during this period (Stegman, 1974; Walmsley and Toerien, 1977; Walmsley, Toerien and Steyn, 1978).

Walmsley, Toerien and Steyn (1978) observed that during events of extreme inflow into the reservoir system, a complex pattern of stratification develops with multiple thermoclines. Under normal conditions of epilimnetic flow, the turbulence created in this region of flow is sufficient to prevent the settling out of particles which fall into the Stokes' Law range of settling velocities (Twenhofel, 1950).

Twenhofel (1932) described the idealised distribution of sediments within lakes (figure 11). The model proposed by Twenhofel holds well when the hydrodynamic conditions of the lake are considered in terms of layered turbulence alone. The outer coarse sediments would be reflective of those deposited above the thermocline and the wave base. The inner, finer sediments reflect those deposited below the thermocline and the wave base. In areas with a wind blowing in one direction only, the belt of coarse material may be developed on only one side of the lake; with steep slopes the coarse grained belt might be completely absent. Many lakes show the sediment distribution proposed by Twenhofel, e.g. Lake Constance (Reineck and Singh, 1973).

In addition to energy provided by direct thermal activity and from wind, sediment and energy are introduced into reservoirs by flow of water from tributary streams and from direct overland flow at times of heavy rainfall. The processes of reservoir deposition following

SCHEMATIC DISTRIBUTION OF SEDIMENTS IN A LAKE (Twenhofel, 1932)

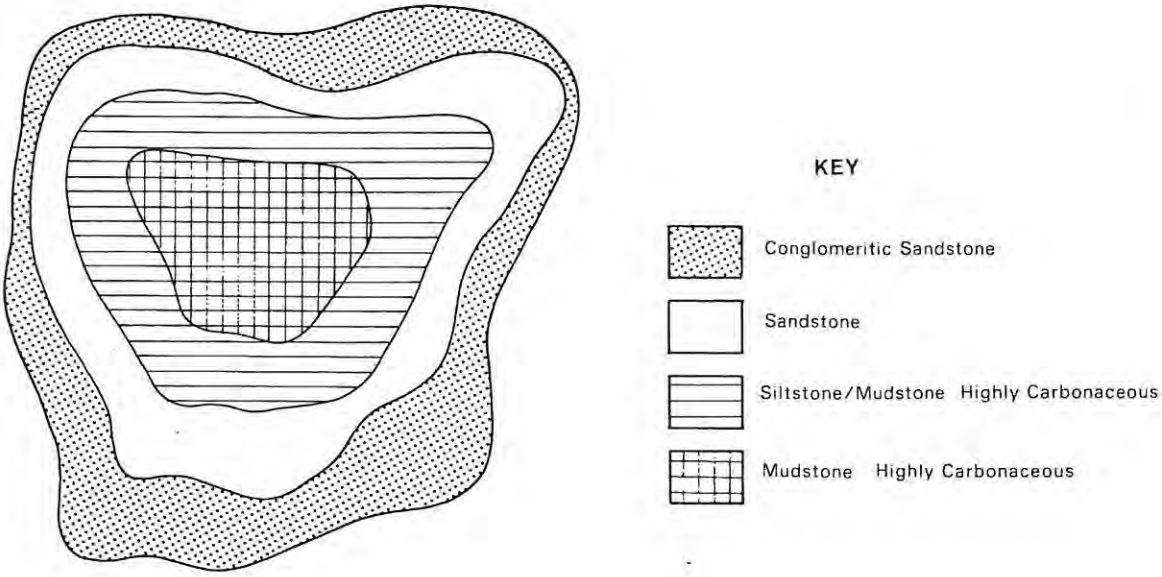


Figure 11.

SCHEMATIC DRAWING OF THE SEDIMENT ACCUMULATION IN A TYPICAL RESERVOIR (Linsley and Franzini, 1972, p.172)

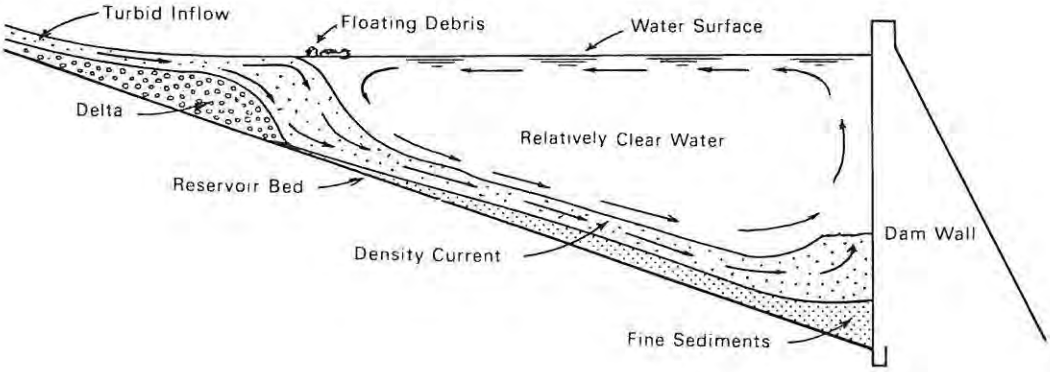


Figure 12.

the introduction of the sediment have been discussed elsewhere in this chapter (2.1). This pattern of sedimentation described by Twenhofel would be found in lakes or reservoirs where all turbulence is initiated by thermal and wind induced energy. In most reservoirs two forces are therefore in operation; those originating from within the water body and those of external origin. The effects of epilimnetic mixing and wave action or marginal sediments must therefore be considered in conjunction with sediment deposition in deltas and by density currents when interpreting reservoir sedimentary environments.

(d) Summary

Section 2.1.1. of this chapter describes mechanisms of deposition of sediment in reservoirs and concludes with the general observation that reservoir sediment would decrease in grain size with distance from the point of input. Section 2.1.2. pointed out the fact that this general trend was complicated due to (i) the presence of two separate sub-environments of deposition and (ii) due to wind and thermally induced water circulation patterns. Figure 12 provides a schematic representation of the overall patterns of sediment accumulation within a typical reservoir.

Although there is a general trend of decreasing sediment grain size from the point of entry to the reservoir wall, there will be two separate groups of sediments within this trend. The groups will be distinguishable mainly due to differences in sorting values and mean grain size.

The sedimentary pattern shown in figure 12 appears to contradict that described by Twenhofel (figure 11) in a number of ways. Neither of the patterns described by figures 11 or 12 are fully acceptable. An ideal description of the distributional patterns of reservoir sediments

is likely to be provided by a model combining deltaic deposits, density current deposits and marginal deposits. Marginal conditions include the effects of wind and temperature as well as areas intermediate to these two regions.

2.2 The Distribution of Biogenic Sediment in Reservoirs.

Biogenic sediments are those sediments composed of plant and animal matter (Allen, 1970, p. 47). Published research on reservoirs make little (if any) mention of the biogenic contribution to sediment accumulation. A plea for the study of distribution of biogenic matter in lakes was made by Frey (1974). It is surprising that there has been little work in this sphere as much reservoir sediment is composed of a mixture of organic and inorganic material. From the available literature it appears that stream-borne biogenic material represents a very small fraction of the total sediment load of streams. The average proportion of biogenic matter carried in most streams varies between 10 and 30 p.p.m. (Blatt, Middleton and Murray, 1972). Menne and Kriel (1959), in their map of the sediment production of streams in South Africa estimate the average sediment content of the streams in the Grahamstown district to vary between 10 000 and 35 000 p.p.m. The proportion of biogenic to total sediment matter based on the above figures could be expected to be 0,03% to 0,3%. This is a relatively small amount of sediment and the proportion of this amount actually retained can be expected to be even smaller due to the likelihood of part of this sediment either passing through the reservoir or decaying.

Evidence from research done by limnologists and sedimentologists working on lakes and reservoirs indicate higher concentrations of biogenic matter than is shown above. Wood (1964) found proportions of up to 7,87% in Saginaw Bay (Lake Michigan). Trout Lake (Wisconsin, U.S.A.) was found to have biogenic concentrations of up to 20% (Rodel, Armstrong and Harris, 1977). Zapol'sky and Yes'kov (1976) found the biogenic content of the sediments of the Kiev Reservoir (on the Dnieper) to vary between 2% and 70%.

It is likely that in addition to biogenic material entering as part of the stream load, a certain amount of material is generated from within the reservoir itself. Two groups of biogenic sediment are likely to form within reservoirs. These groups can be classified according to their position of deposition relative to the water surface and their manner of deposition. Allochthonous limnic deposits can be expected in areas below low water levels. These deposits are typically very fine and unidentifiable (West, 1969). They are termed allochthonous as they are deposited distal to their point of growth. Autochthonous, semi-terrestrial deposits are formed in areas between the low and high water levels. These deposits are typically coarse and identifiable as they are deposited at the point of plant growth (West 1969). In both cases, the sediments are prevented to a certain extent from decay by oxidation because of the protection given by the water body (West, 1969). Collingwood and Davis (1978) observed that if wind does not often occur in the summer months, decomposition of organic matter in the epilimnion depletes the store of oxygen available for decomposition in the hypolimnion. The degree of oxidation of allochthonous sediments will, therefore, vary with depth. This observation supports Twenhofel's (1932) model of sediment distribution in lakes (figure 11). As with distribution of mineral sediment in reservoirs, this pattern will be affected by external forces such as entering streams and thermally and wind induced circulation of water.

A study of the texture and proportion of biogenic sediment coupled with a study of texture of mineral sediment will provide a clearer indication of the relative importance of the two classes of biogenic sediment. A correlation between fine grained mineral deposits and % biogenic matter has been observed by numerous workers (Wood, 1964; Coakley and Rust, 1968 and Zapol'sky and Yes'kov, 1976). The correlation is generally attributed to the specific gravity of the two sediment types. Hansen (1959) found that humus colloids have an average specific gravity of 1,1. Inorganic sediments are generally assumed to have a mean specific gravity of 2,65. Allochthonous biogenic sediment will therefore only settle out of suspension in areas of extremely low energy conditions; i.e. adjacent to the fine inorganic sediment. This reasoning can be applied to allochthonous biogenic sediments but not to autochthonous biogenic sediments. The latter are found in shallower reaches of reservoirs and due to their proximity to source areas of inorganic sediment, are likely to be deposited alongside coarse inorganic sediment.

If it is found that the proportion of biogenic sediment is large, then it might well be that predictive volume displacement models based on sediment generated outside the reservoir underestimate the amount of sediment accumulating in reservoirs.

2.3 The Use of Grain Size Parameters in Interpreting Sedimentary Environments in Reservoirs.

It is very difficult to measure directly the processes of reservoir sedimentation. Most of the theory relating to sedimentation processes is derived from a combination of observations made in flume experiments and deductive reasoning (Einstein and Johnson, 1950; Graf, 1971; Borland, 1971 (in Roosenboom, 1975)). There is at present no completely satisfactory theory on sediment movement through reservoirs (Roosenboom, 1975); according to Graf (1971) there is as yet little scientific proof that the relatively simple uniform current theory is indisputable (Roosenboom, 1975). The need for field evidence to substantiate existing theory is therefore real (Einstein and Johnson, 1950; Roosenboom, 1974).

In providing measurements of the attributes and characteristics of sediments, grain size measurement has been standard practice for many years and is one of the most commonly measured parameters in sediment and weakly consolidated rocks (Royse, 1968). Approximately 80% of the published work (Pettijohn, Potter and Siever, 1972) has been undertaken with the aim of seeking information which may be interpreted in terms of processes of sedimentation; "... the underlying assumption being that the physical processes at the site of deposition impart a distinctive textural "fingerprint" to the sands ...", elucidating the environment at the time of deposition (Pettijohn, Potter and Siever, 1972, p. 68).

Environments of deposition occurring within reservoirs were discussed in the first part of this chapter (2.1) and particular reference was made to the variation of grain size parameters associated with each different environment. The following discussion considers grain size parameters used by sedimentologists with special reference to those used in the present study.

2.3.1. <u>The concept of grain size</u>

A universal definition of grain size is difficult due to the variability of grain shape. If all sediment particles were spheres or cubes there would be little difficulty in defining their grain sizes. "Conceptually there is an intuitive belief that size refers to bigness, but no clear definition has been given or can be given except by comparison to some reference standard" (Griffiths, 1967, p. 43). The basic concept of size is considered to be either a linear measurement or a measure of the volume of the particle. Failure to recognise the fact that various measures of size are based on different concepts of size has been a point of much controversy amongst research workers (Griffiths, 1967; Weaver, 1977). It is therefore of fundamental importance to state what component of grain size is being measured at the outset of sediment analysis.

2.3.2. Units of measure of grain size

Various size terms have been adopted by sedimentologists. This section defines precisely the meaning of the parameters used in this study. It is commonly accepted that a geometric expression of mineral grain size is preferable to a linear expression, because, for example, the difference between grains of 1 mm and 6 mm is obviously more significant than the difference between grains of 100 mm and 106 mm (Blatt, Middleton and Murray, 1972). Udden (1898) realized the need for a logarithmic scale and devised a scale based on a centre of 1 mm and a multiplier, or divisor of 2. This scale was modified by Wentworth (1922) and later by Lane (1947) and is still commonly used today.

In 1943 Krumbein introduced a logarithmic transformation of the Udden-Wentworth-Lane scale, which he named the phi (ϕ) scale:

$$\phi = - \log_2 d.$$

where d = diameter in millimeters.

Table 1 shows the relationship between Udden-Wentworth-Lane class limits and the phi scale.

TABLE 1 RELATION BETWEEN UDDEN-WENTWORTH-LANE CLASS LIMITS, PHI SCALE AND MILLIMETRES

Wentworth-Lane Class		phi Units	Millimetres
		greater than	greater than
Boulders		-8	256
Cobbles	large	-7 to -8	128 to 256
	small	-6 to -7	64 to 128
Gravel	very coarse	-5 to -6	32 to 64
	coarse	-4 to -5	16 to 32
	medium	-3 to -4	8 to 16
	fine	-2 to -3	4 to 8
	very fine	-1 to -2	2 to 4
Sand	very coarse	0 to -1	1 to 2
	coarse	1 to 0	1/2 to 1
	medium	2 to 1	1/4 to 1/2
	fine	3 to 2	1/8 to 1/4
	very fine	4 to 3	1/16 to 1/8
Silt	coarse	5 to 4	1/32 to 1/16
	medium	6 to 5	1/64 to 1/32
	fine	7 to 6	1/128 to 1/64
	very fine	8 to 7	1/256 to 1/128
Clay	coarse	9 to 8	1/516 to 1/256
	medium	10 to 9	1/1024 to 1/516
	fine	Less than 10	Less than 1/1024

Blatt, Middleton and Murray (1972) list the three main advantages of the phi scale as:

(i) "The main points on the Udden-Wentworth scale become whole numbers instead of fractions.

(ii) "The scale is reversed so that the larger sizes, which are conveniently plotted on the left by geologists, become negative and the smaller sizes become positive numbers on the phi scale.

(iii) "Use of the phi scale permits use of arithmetic rather than logarithmic graph paper and simplifies the calculation of both graphic and numerical descriptive statistics, such as mean; standard deviation, skewness and kurtosis" (Blatt, Middleton and Murray, 1972, p. 47).

The present study makes use of the phi scale. Where a verbal description of the sediment grain size is used, reference is made to the Udden-Wentworth-Lane class limits (Table 1) as this is the most universally used grain size classification.

2.3.3. Grain size frequency distributions and parameters

(a) Graphical representation

The size distribution of a sediment sample can be graphically represented as a table, a histogram, a size frequency curve or a cumulative curve. Cumulative curves are "... widely, if not universally used by students of the granular materials" (Pettijohn, 1957, p. 34). Once the sediment sample has been analysed and the proportion of sediment representing each grain size class has been assessed (e.g. weight retained on each sieve); the percentage smaller than each of these grain size classes is calculated. These percentages are plotted on the vertical scale against the corresponding size classes which are plotted on the abscissa. The curves

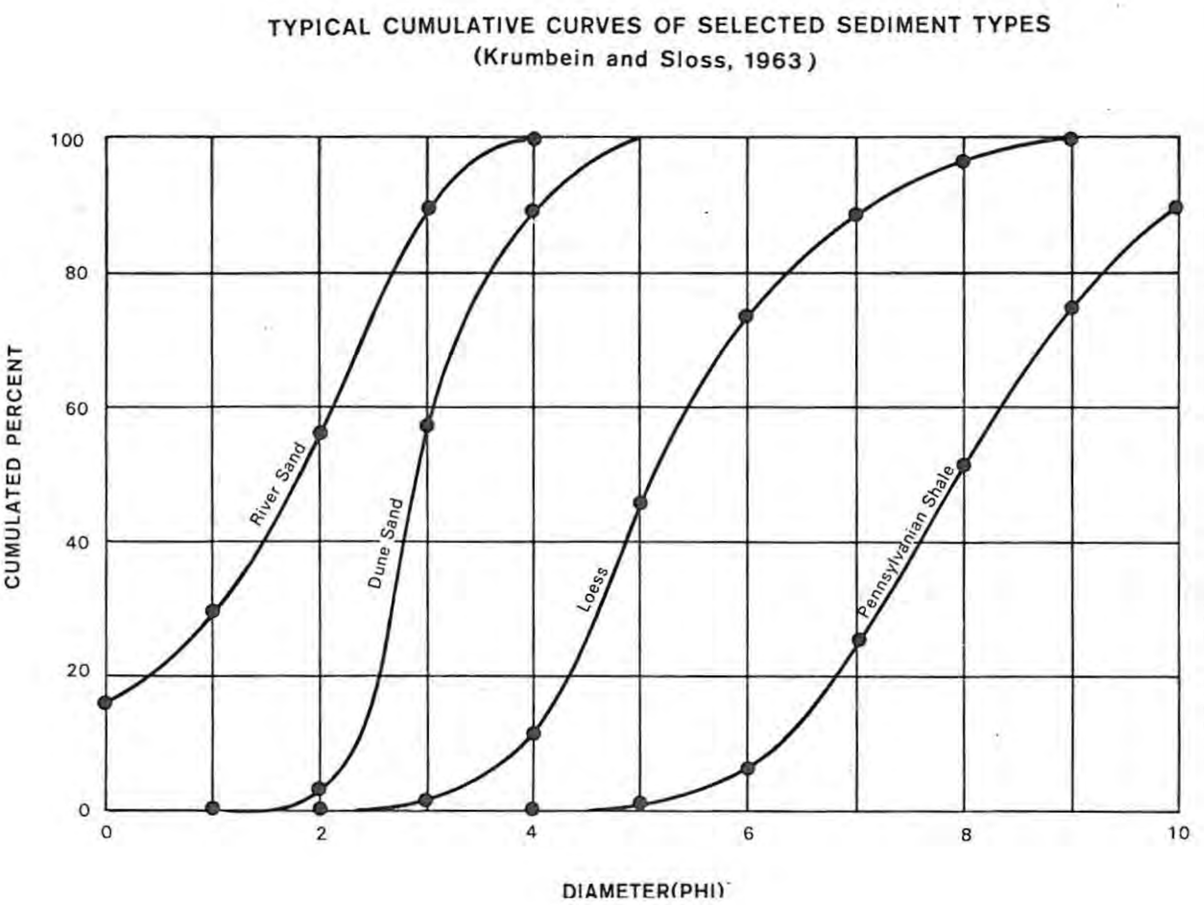


Figure 13.

are commonly plotted with the cumulative frequency on a "probability" scale. If the distribution of sediment grain sizes occurs as a normal (Gaussian) frequency, the cumulative curve will plot as a straight line (Blatt, Middleton and Murray, 1972). The use of cumulative frequency curves facilitates both visual and statistical description of non-normal distribution as is demonstrated by the selection of sediment types depicted in figure 13.

(b) Grain size parameters

The chief moment parameters of the cumulative frequency curve as proposed by the major workers in this field are shown in Table 2.

Folk and Ward and McCammon moment parameters were calculated in the present study. These measures are the more precise of the moment parameters available (King, 1966).

TABLE 2 PARAMETERS OF SEDIMENT-SIZE DISTRIBUTION ACCORDING TO SEVERAL AUTHORS.

Measure	Trask	Inman (1952)	Folk & Ward (1957)	McCammon (1962)
Median	$Md = P^{+}50$	$Md\phi^{*} = \phi 50$	$Md\phi = \phi 50$	
Mean	$M = \frac{P25+P75}{2}$	$M\phi = \frac{\phi 16+\phi 84}{2}$	$M_z = \frac{\phi 16+\phi 50+\phi 84}{3}$	$(\phi 5 + \phi 15 + \phi 25 + \phi 35 + \phi 45 + \phi 55 + \phi 65 + \phi 75 + \phi 85 + \phi 95)/_{10}$
Sorting	$So = \frac{P75}{P25}$	$\sigma\phi = \frac{\phi 84-\phi 16}{2}$	$\sigma_1 = \frac{\phi 84-\phi 16}{4} + \frac{\phi 95-\phi 5}{6{,}6}$	$(\phi 70 + \phi 80 + \phi 90 + \phi 97 - \phi 3 - \phi 10 - \phi 20 - \phi 30) + 9.1$
Skewness	$Sk = \frac{P25\ P75}{Md^2}$	$\sigma\phi = \frac{M\phi-Md\phi}{\phi}$ $\sigma_{2\phi} = \frac{\frac{1}{2}(\phi 5+\phi 95-Md)}{\sigma\phi}$	$Sk_1 = \frac{\phi 16+\phi 84-2\phi 50}{2(\phi 84-\phi 16)} + \frac{\phi 5+\phi 95-2\phi 50}{2(\phi 95-\phi 5)}$	
Kurtosis	$K = \frac{P75-P25}{2(P90-P10)}$	$\beta\phi = \frac{\frac{1}{2}(\phi 95-\phi 5)-\sigma\phi}{\sigma\phi}$	$K_G = \frac{\phi 95-\phi 5}{2.44(\phi 75-\phi 25)}$	

+ P indicates a percentile measure, measured in millimeters.

* ϕ indicates a ϕ percentile.

Folk and Ward and McCammon values produced almost identical values. It was therefore decided to use Folk and Ward values only as they are the most widely used measures (King, 1966).

2.3.4. The interpretation of grain size parameters

Generally, the mean and skewness values are the only values used independently in sediment studies. Other parameters are generally used in conjunction with each other. This section discusses the various grain size parameters with respect to the depositional processes reflected by each parameter or combination of parameters.

(a) Average grain size

The two measures commonly used for expressing the average grain size of sediments are the median and the mean. The median is an easily determined value represented by the 50% value on the cumulative frequency curve. The median measure does not, however, take into account the spread of the sediment distribution on either side of the 50% value. The mean grain size is, therefore, generally accepted as a better reflection of the central tendency of the cumulative curve (McBride, 1971).

In investigations of sediment transport and deposition in water, mean grain size may give indications of the distance of the sediment from its source, and the type of transport. Mean grain size is used as a basic descriptive tool and as a variable to be related to other properties (e.g. biogenic content) so that variations in these properties can be predicted from variations in mean grain size (Blatt, Middleton and Murray, 1972). Grain size is of particular use in the present study as the size distribution of sediment in reservoirs is particularly dependent on the motion of the water in which the sediment accumulates (Trask, 1950). Mean grain size is used as a variable to be related to variations in biogenic proportions of sediment so that a better understanding of the origin and distribution of biogenic matter can be acquired.

(b) Kurtosis

Kurtosis is a dimensionless value which shows the peakedness of a distribution. "It is assumed that Kurtosis is a moment measure indicating environmental conditions ..." (Stephenson, 1970, p. 201). There is some uncertainty about the actual meaning of a given kurtosis value. Little work has been done on kurtosis and that which has been done shows little sedimentological significance (Blatt, Middleton and Murray, 1972). The contrast between two symmetrical distributions that differ in kurtosis but which have identical mean and median values is shown in figure 14. The present study includes calculations of kurtosis in order to provide a full description of samples and so that possible future studies in a similar field can use the data on a comparative basis.

TWO SYMMETRICAL DISTRIBUTIONS THAT DIFFER IN KURTOSIS
(Blatt, Middleton and Murray, 1972)

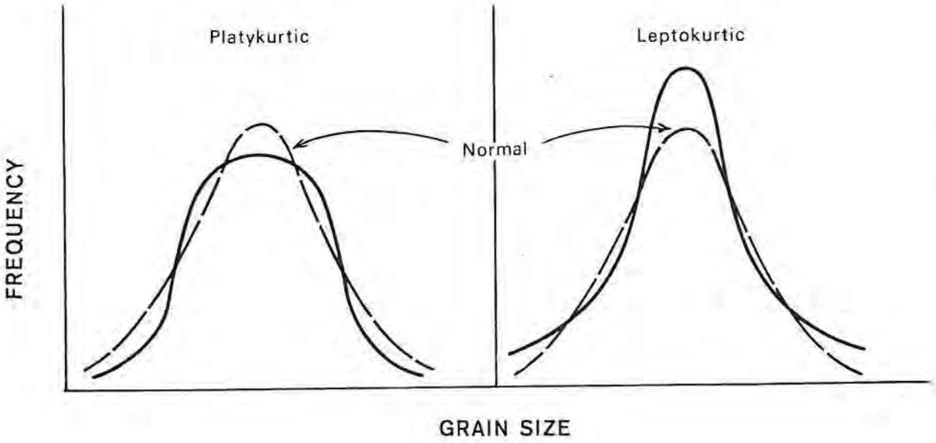


Figure 14.

(c) Skewness

Skewness is a measure of the distribution of the sample around the mean and may be related to environmental energy (Stephenson, 1970). A distribution exhibiting perfect symmetry has a skewness value of zero, and all other values are either positive or negative depending on the direction in which the curve is skewed (figure 15). With positive skewness the coarser sediment component as a percentage of the total excedes the finer component. With negative skewness the converse is true.

POSITIVELY AND NEGATIVELY SKEWED SEDIMENT SAMPLES
(Blatt, Middleton and Murray, 1972)

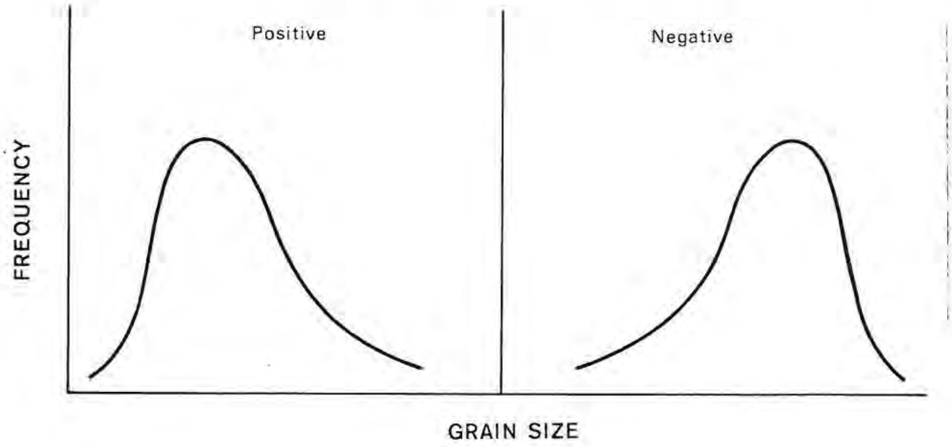


Figure 15.

A perfectly symmetrical distribution of sediment grains within a sample is extremely rare. Skewness and kurtosis are, therefore, useful para= meters for describing the assymetry of sediment samples.

(d) Sorting

Sorting measures the degree of spread or standard deviation of the distribution of sediment particles within the sample (Stephenson, 1970). Folk and Ward (1957), based on numerous analyses from many different environments, suggested a verbal division for sorting values (Table 3).

TABLE 3 VERBAL DESCRIPTION OF SORTING (Folk and Ward, 1957, p. 13).

Sorting Value	Verbal Description
under 0,35	very well sorted
0,35 to 0,50	well sorted
0,50 to 1,00	moderately sorted
1,00 to 2,00	poorly sorted
2,00 to 4,00	very poorly sorted

Sorting is a particularly useful parameter in describing the effect of flow conditions on sediment deposition. Hydraulic flow is an extremely effective sorting agent as it groups together particle sizes that respond to flow in a similar manner and, at the same time separates them from particles that respond differently to the flow (Blatt, Middleton and Murray, 1972). Well sorted sediment indicates constant hydraulic flow conditions and poorly sorted sediment indicates fluctuating hydraulic flow. Trask (1950) observed that slowly moving water leads to poorer sorting than fast moving water.

2.3.5. <u>The conjunctive use of grain size parameters</u>.

The description of sedimentary characteristics based upon the combined parameter values derived from grain size analysis provides an important component of much sedimentological investigation. The following section outlines the combined parameters used in this study.

(a) Mean grain size and sorting

Rukhin (1947) was able to distinguish between different areas of sedimentation by plotting phi mean against phi sorting. The method has been subsequently used by numerous sedimentologists (for example Inman and Chamberlain, 1956; Stewart, 1958; Cadigan, 1961; Dickinson, 1968). The relationship between sorting and mean grain size was explained by Inman (1949) who pointed out that because of the relation= ship exhibited by Hjulstrom's diagram (figure 7), fine sand is the most easily moved sediment. Sediments coarser than this are moved by currents that also carry and deposit finer materials. Figure 16 shows an example of the correlation that exists between sorting and mean diameter as obtained by King (1966) from sediments from offshore in Lincolnshire.

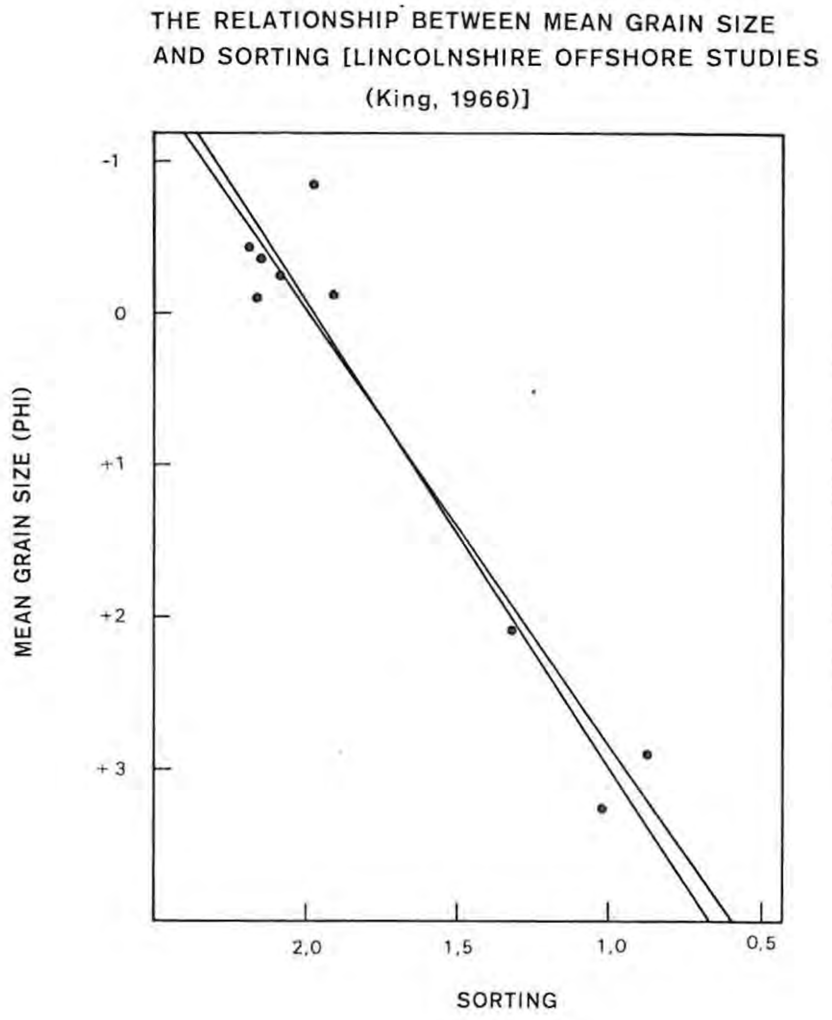

THE RELATIONSHIP BETWEEN MEAN GRAIN SIZE AND SORTING [LINCOLNSHIRE OFFSHORE STUDIES (King, 1966)]

Figure 16

Griffiths (1961) observed that any sediments which depart from this trend are related to abnormal events in the history of the deposit. Flocculation of fines provides an example of such an anomaly. In chapter 2.1.2. it was noted that reservoir deltas are typically made up of well sorted (relatively) coarse sediments whereas density current deposits are poorly sorted (relatively) fine sediment deposits. A correlation between mean and sorting parameters should therefore, be a useful tool in deliniating subenvironments of deposition within reservoirs.

(b) Sorting and Skewness

More subtle differences between sediments may be revealed by comparing selected parameter values. Friedman (1961) was able to distinguish between dune, beach and river sands by plotting sorting against skewness (figure 17). Beach sands show negative skewness and good sorting whereas river sands are generally positively skewed and less well sorted. Koldijk (1968) also observed the usefulness of this combination when distinguishing between environments of deposition.

DISTINCTION BETWEEN BEACH AND RIVER SANDS ON THE BASIS OF SKEWNESS AND SORTING (Friedman, 1961, in Blatt Middleton and Murray, 1972, p.60)

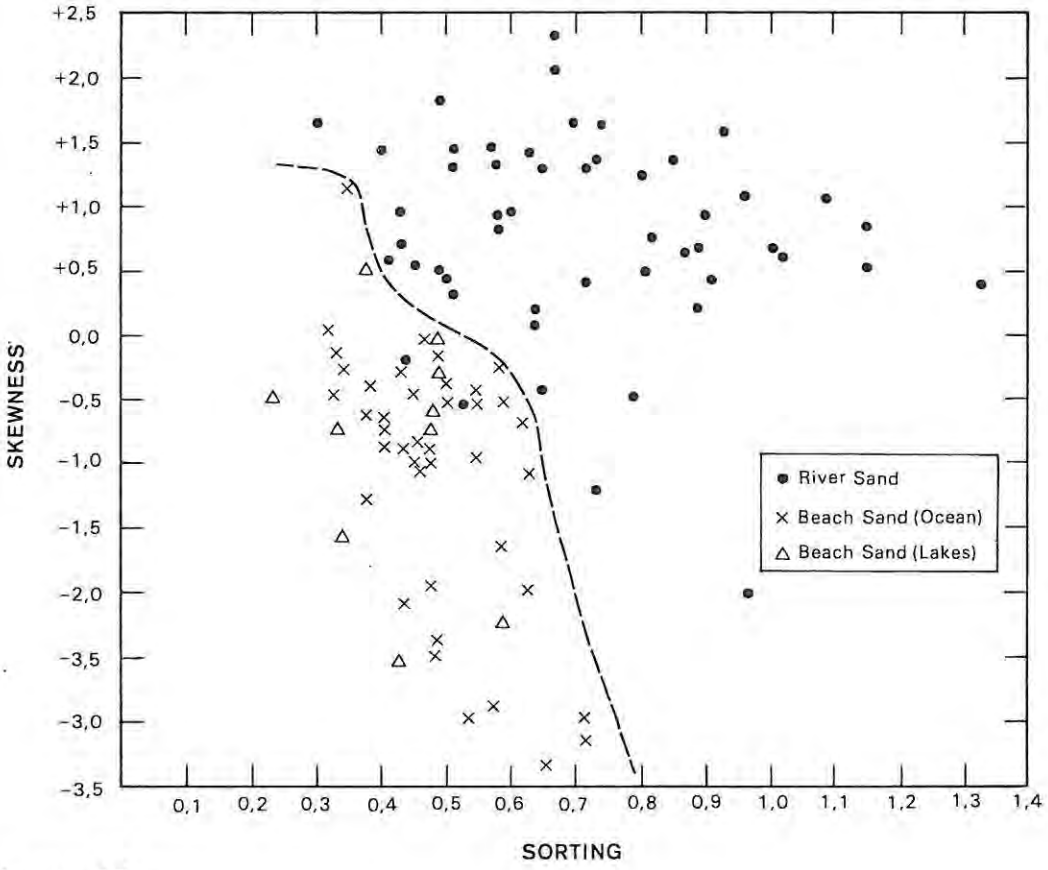


Figure 17

(c) Pattern C.M. analysis

A little used, but increasingly popular sedimentation index was devised by Passega (1957, 1964). The method of Passega's Pattern C.M. analysis is described by Royse as being "... plots of samples from known environments in which the smallest particle size in the coarsest one percentile (C) of the size distribution was plotted as a function of the median grain size (M). The value of C was representative of the (minimum) competence of the transporting agent and M is a statistic characteristic of the total range of the particle sizes undergoing transport by this agent" (Royse, 1968, p. 1177). One of the advantages of Passega's scheme is that it makes use of the coarsest and median sizes, both of which may be accurately measured. Royse (1968), Williams and Rust (1969) and Allen (1971) successfully applied C.M. pattern analysis to braided rivers, estuaries and fluvial environments respectively. C.M. patterns provide an extremely useful tool in recognizing various sedimentary subenvironments. Discrimination between environments is not made on the basis of one sample, but by plotting numerous samples from the same unit. The generalized patterns which emerge from C.M. pattern analysis are shown in figure 18. C.M. patterns should prove to be a useful tool for the identification of sub-environments of deposition within a reservoir.

2.4. Process-Response Models of Sedimentary Environments

Krumbein and Sloss (1964) created a generalized model of sedimentary environments. The model is based on processes at work in sedimentary environments and the sedimentary products (response) arising from these processes. The foregoing sections of this chapter summarized the theorectical background to the sedimentary processes typical of the reservoir environment. The present section describes the Krumbein and Sloss model with particular emphasis on the process and response elements present in reservoirs. Process and response analysis forms the basis of much of the present study.

CM PATTERNS OF SEDIMENTS DEPOSITED IN DIFFERENT ENVIRONMENTS (Passega, 1957)

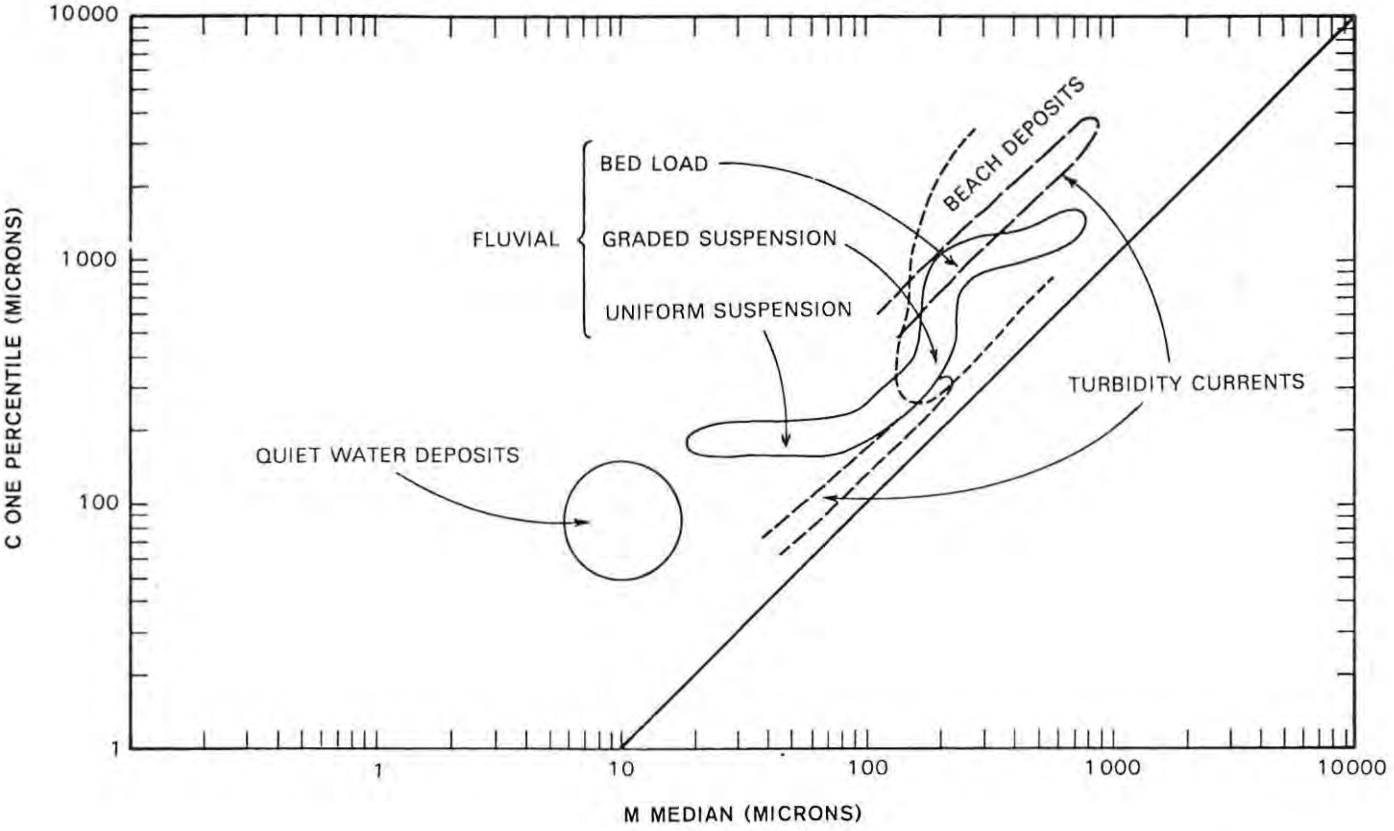
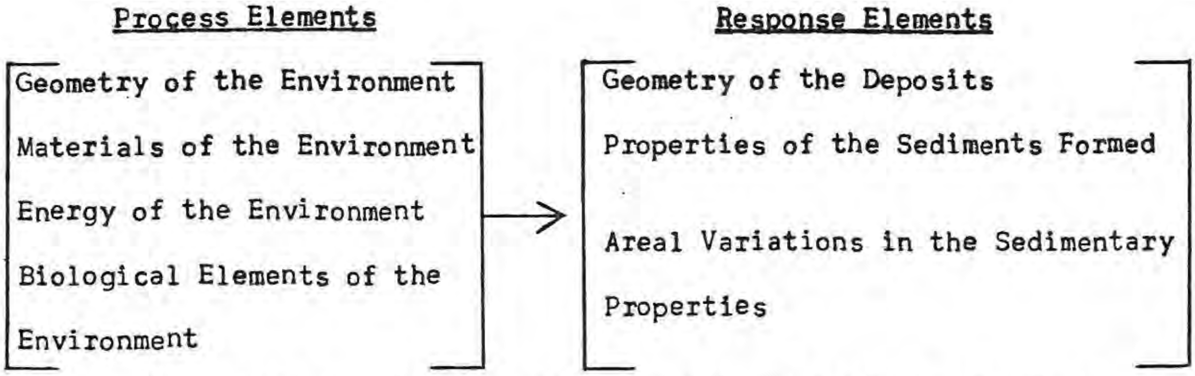


Figure 18

In order to understand the relationship between sedimentary properties and the processes that control them, it is necessary to study simultaneously environmental processes and their products. A process-response model should facilitate examination of the relationships which exist between environmental attributes and the corresponding sedimentary attributes. Figure 19 illustrates the schematic arrangement of the Krumbein and Sloss process-response model. The figure lists the elements contained in the process-response model. Specific aspects of the elements listed are termed environmental factors.

Figure 19: A GENERALIZED SEDIMENTARY ENVIRONMENT PROCESS-RESPONSE MODEL. (KRUMBEIN AND SLOSS, 1964, P. 237)



The environmental elements and their constituent factors present in reservoirs are:

2.4.1. Geometry of the environment/boundary conditions.

These include the depth of the water, the shape of the reservoir, the configuration of the depositional surface and the proximity of the reservoir banks. The geometry of the environment defines the physiographical framework of the environment.

2.4.2. Materials of the environment.

In general, this includes the medium of sedimentation and the texture and composition of the material in transit or being deposited. More specifically, in the reservoir system, this includes:

(a) Water
(b) Biogenic Sediment
(c) Clastic Sediments, i.e.: sands, silts, clays.

2.4.3. Energy of the environment.

(a) Thermal energy

1. Most noticeably solar radiation resulting in epilimnetic turbulence.
2. Other thermal energy generated by friction at boundary contacts is dissipated in the environment and is not documented in the literature as playing an important role in influencing response elements.

(b) Mechanical energy

1. Turbulent energy in deltaic sub-environments
2. Density current flow
3. Kinetic energy of winds
4. Waves

2.4.4. Biological elements.

Biological elements have varying effects by adding biogenic sediment to inorganic deposits. Living organisms sometimes disturb existing clastic deposits. For the sake of simplicity, the present study considers only deposited biological elements; this material can be divided into two groups:

a. Allochthonous biogenic deposits

b. Autochthonous biogenic deposits

Krumbein and Sloss add a feedback loop to the model discussed above (figure 20).

Figure 20: THE FEEDBACK LOOP TO THE PROCESS-RESPONSE MODEL.

The feedback loop constantly functions in reservoir systems. When, for example, delta building extends into the reservoir and shallow water, high energy conditions are created, the response elements of the model cause a feedback which in turn affects the process elements.

The understanding of sedimentary environments depends strongly on the correlation between process and response elements. The study hypotheses are formulated in chapter 4 with the specific intention of testing the relationships between process and response elements in the reservoir environment.

CHAPTER 3

STUDY AIMS

The aims of the study are:-

1. To provide a scientifically based, reasoned explanation of the characteristics of the surficial sediments of the Howison's Poort reservoir. In particular the investigation aims to determine the variations in areal distributions of inorganic sediment and variations in biogenic proportion of the total sediment.

2. To examine the extent to which variations in sedimentary characteristics can be explained by the existing theories on the mechanisms of reservoir sedimentation and reservoir water circulation.

3. To assess the applicability of grain size parameters in the identification of sedimentary patterns within the reservoir.

In the following section a number of hypotheses are proposed in order to test the existence of relationships between sedimentary characteristics and processes of deposition and to assess the strength of these relationships.

CHAPTER 4

STUDY HYPOTHESES

4.1 The Hypotheses

1.a. "There is an inverse relationship between the distance from the nearest reservoir bank and the mean grain size of inorganic sediment."

b. "There is an inverse relationship between the distance from the nearest reservoir tributary and the mean grain size of inorganic sediment."

c. "There is an inverse relationship between the distance from the main tributary and the mean grain size of inorganic sediment."

d. "There is an inverse relationship between the water depth and the mean grain size of inorganic sediment."

2. "There exist two groups of sediment exhibiting distinctive textural characteristics."

3.a. "The proportion of biogenic material at a given point in the reservoir is directly related to the distance from the nearest reservoir bank."

b. "The proportion of biogenic material at a given point in the reservoir is directly related to the distance from the nearest reservoir tributary."

c. "The proportion of biogenic material at a given point in a reservoir is directly related to the distance from the main tributary."

d. "The proportion of biogenic material at a given point in the reservoir is directly related to the water depth at that point."

4.a. "Covariance exists between the proportion of biogenic material in reservoir sediment and the mean grain size of inorganic reservoir sediments."

b. "Covariance exists between the proportion of biogenic material in reservoir sediment and the sorting values of the inorganic reservoir sediment."

4.2. Derivation of the Study Hypotheses

The above hypotheses are all based on the theoretical background to the study presented in chapter 2. For the sake of convenience, the hypotheses are subdivided into four broad categories; distribution of inorganic sediment, identification of sub-enviroments of deposition, distribution of biogenic material and the relationship between grain size parameters and the proportion of biogenic sediment. This section discusses the hypotheses in these categories identifying the theory upon which they are based.

4.2.1. Distribution of inorganic sediment

Hypotheses 1a,b,c and d relate grain size of inorganic sediment to the spatial location of the sediment. These hypotheses are based on the information presented in chapter 2.1.1. where it was theorised that the mean grain size of the inorganic sediment decreases with distance from its source and with decreasing energy conditions. Due to difficulties in isolating one variable to describe this change, all areas of high energy conditions and sources of sediment are considered; i.e. the banks, the sub=tributaries, the main tributary and the shallow water areas. Because of the great difference in catchment size of the reservoir tributaries (chapter 1), it is likely that the main tributary stream provides the great majority of water and, therefore, sediment to the reservoir. For this reason, consideration of the sedimentological influence of the main tributary is given separately to that of the sub-tributaries. The hypothesized relationship between depth and mean grain size of inorganic sediment is based on the assumption that energy conditions in deep water are liable to be lower than those in shallower reaches where fine sediments are likely to be maintained in suspension by epilimnetic turbulence.

4.2.2. Identification of sub-environments of deposition

Hypothesis 2 is based on the information provided in chapter 2.1.2. Chapter 2.1.2. discusses the distribution of sediments in reservoirs and concludes that, according to the available literature, there are two separate depositional agents at work in reservoirs; resulting in deltaic-type and density current-type deposits. Chapter 2.3. discusses various grain size parameters and the conjunctive use of these parameters as tools in distinguishing sedimentary environments of deposition. Grain size parameters will be conjunctively used to test the validity of the theory that two separate environments of deposition exist within the reservoir sediment environment.

4.2.3. Distribution of biogenic sediment

The distribution of biogenic sediment is discussed in chapter 2.3. Due to the low specific gravity of biogenic material (1,10) as compared to that of inorganic material (2,65), the former can be expected to settle out in areas of extremely low energy conditions. Biogenic material will therefore settle out in areas where fluid motion approaches laminar flow (chapter 2.1.1). Such conditions are most likely to exist in areas distal to the reservoir banks, the tributary streams and in areas of deep water. Hence the formulation of hypotheses 3a,b,c and d.

4.2.4. The relationship between grain size parameters and the proportion of biogenic sediment.

In chapter 2.3.1., it ~~is~~ noted that grain size parameters can be used as variables to be related to other properties and that variations in these properties may be predicted from variations in grain size parameters. In chapter 2.3.5. the relationship between mean grain size and sorting was discussed. Assuming that small mean grain size, poor sorting values and the occurrence of allochthonous biogenic sediment are reflective of low energy conditions, it follows that mean grain size and sorting parameters will covary with the proportion of allochthonous biogenic sediment. Hence the formulation of hypotheses 4a and b.

CHAPTER 5

DATA COLLECTION

Two types of data are needed to test the study hypotheses presented in chapter 4; field data and laboratory data. Field data includes an accurate survey of the bottom topography of the reservoir and the positioning of sampling points. Laboratory data includes the analysis of the sediment samples for grain size characteristics and for biogenic content. This chapter outlines the methods used in the collection of field and laboratory data.

5.1. Field Data

The field data needed for the completion of the study includes survey data and the positioning and collection of sediment samples.

5.1.1. Survey data

The precise location and depth must be known for each sample point, an accurate areal and depth survey was therefore necessary. Previous surveys were taken in 1951 and 1953 by the Grahamstown Municipality. Before the present study could begin, it was necessary to re-survey the entire reservoir due to probable changes in reservoir profile since 1953.

a. Areal survey

A survey base line was established along the dam wall between the same two points that were used in 1953. Where possible, beacons from the 1953 survey were used and fixed; a large number of new beacons had to be established. The total number of beacons fixed was 36. The beacons were sighted and fixed using a theodolite. The beacons were zeroed in using the maximum capacity reading on the reservoir water level plate as "o". A bench marker was established at the survey station so that fluctuations in water levels could be monitored and depth readings could be adjusted accordingly throughout the survey.

b. Depth profiles

A total number of 538 depth soundings was taken along 21 cross sections. A nylon ski rope marked at five metre intervals was winched across the reservoir between opposite beacons until fully taut (plate 2).

Plate 2 : WINCH USED TO SUSPEND THE NYLON ROPE ACROSS THE RESERVOIR.

The distance from each beacon was measured and recorded. Depth readings were taken using a non-stretchable glass fibre tape measure with a weight attached to its base. The survey boat was pulled along the winched rope and depth measurements were taken at 5 metre intervals.

Depth readings were adjusted to depths below the high water level as measured at the bench marker. Very little adjustment of readings was necessary (0,05 m) as the water-level of the reservoir remained fairly constant throughout the survey period. A contour map of the reservoir was constructed from the survey data (figure 21). The storage capacity of the reservoir was calculated using a computer program which utilizes the trapezoidal method of capacity calculation. The present capacity of the reservoir was calculated to be 802 765 m^3; i.e. 97 335 m^3 less than the total calculated in 1953. Assuming the 1953 data to be accurate, the average sedimentation rate over the past 25 years has been 3893,4 m^3 per year. This rate of sedimentation represents a storage capacity loss of ,433% per year.

Distances to the nearest banks, tributaries and main tributary as well as depth measurements were measured directly from the survey map (figure 21) and are recorded in the data table (table 4, p.54).

5.1.2. Sediment sampling

The collection of sediment samples was undertaken between 30th May and 5th June 1978.

a. Sampling technique

The sediment samples were collected using a specially designed jaw grab (plate 3). The grab is designed to extract approximately 1 000 grams of sediment from the top 10 cm of reservoir sediment. Samples were only obtained from the surface layers of the sediment because of:

(i) The difficulties and costs involved in obtaining core samples,

(ii) The fact that the present study is concerned with spatial variations and not temporal variations in sediment patterns (as would be reflected by core samples).

TABLE 4 : FIELD AND LABORATORY DATA FOR THE HOWISON'S POORT RESERVOIR.

1 Sample Location	2 Sample Number	3 Nearest Bank (m)	4 Nearest Tributary (m)	5 Nearest Tributary in Sub-Catchment (m)	6 Main Tributary (m)	7 Depth (m)	8 Percent Biogenic Material	9 Kurtosis	10 Mean ø	11 Sorting	12 Skewness	13 Median ø	14 Coarsest Percentile ø
1	LSRS00	4,8	16,8	16,8	16,8	0,60	1,20	0,869	1,870	0,486	0,000	1,870	0,946
2	LSRS01	4,8	28,8	28,8	28,8	1,30	0,63	2,152	1,783	0,911	-0,367	1,750	0,900
3	LSRS04	12,0	48,0	48,0	48,0	1,50	3,13	1,218	3,234	1,213	-0,355	3,055	0,539
4	LSRS05	9,6	84,0	84,0	84,0	1,27	5,73	0,922	1,900	0,548	-0,056	1,900	0,900
5	LSRS06	12,0	98,0	98,0	98,0	1,52	0,34	0,817	2,555	0,346	-0,029	2,555	0,378
6	LSRS07	15,6	114,0	114,0	114,0	1,79	0,92	0,922	2,252	0,643	0,020	2,263	0,646
7	LSRS08	10,8	122,4	122,4	122,4	1,61	1,67	1,184	2,083	0,666	0,229	2,037	1,082
8	LSRS09	12,0	159,6	159,6	159,6	1,84	1,84	0,809	4,333	1,246	-0,431	3,950	2,600
9	LQRQ05	16,8	182,0	182,0	182,0	2,00	1,27	1,377	3,516	1,096	-0,365	3,370	0,543
10	LQRQ02	20,4	158,4	158,4	158,4	1,51	45,38	0,729	5,791	1,875	-0,004	5,856	1,566
11	LRRR01	10,2	260,5	260,5	260,5	1,48	7,84	0,870	5,629	1,548	-0,129	5,661	2,395
12	LRRR03	30,4	255,7	255,7	255,7	1,60	6,81	1,067	5,564	1,583	-0,023	5,661	2,541
13	LRRR05	13,2	261,7	261,7	261,7	2,25	1,20	0,851	4,979	1,651	-0,267	4,686	1,908
14	LORO06	9,6	260,5	357,7	357,7	2,34	7,59	1,057	5,564	1,867	-0,277	5,125	2,249
15	LORO04	42,0	246,1	348,1	348,1	3,04	6,26	0,883	5,873	1,618	-0,207	5,710	2,297
16	LORO02	20,4	234,1	345,7	345,7	3,04	6,49	1,220	4,930	1,967	-0,660	4,199	0,640
17	LORO01	10,2	232,9	344,5	344,5	2,47	6,49	1,072	5,910	1,922	-0,196	5,956	2,175
18	LNRNR01	10,2	128,4	462,1	462,1	3,71	7,08	0,536	6,409	1,916	-0,043	6,393	2,346
19	LNRN03	30,6	151,2	459,7	459,7	3,84	6,04	0,843	5,986	1,826	-0,236	5,710	2,200
20	LNRN05	36,0	174,0	462,0	462,0	5,32	6,84	1,062	5,824	1,852	-0,057	5,710	1,956
21	LNRN07	6,0	199,3	463,3	463,3	3,67	8,97	0,535	6,490	1,936	-0,023	6,490	2,395
22	LJRJ01	10,2	30,0	30,0	566,5	3,30	9,67	0,909	6,392	2,231	-0,270	6,162	2,313
23	LIRI02	20.4	86,4	86.4	600,2	2,35	6,78	0,947	6,167	2,561	0,206	6,250	0,050
24	LIRI04	40,8	66,0	66,0	561,7	2,05	15,78	0,570	6,555	1,924	-0,019	6,539	2,395
25	LKLL02	24.0	135,6	135,6	624,2	4,46	10,91	0,778	6,027	2,527	-0.710	4,320	0,320
26	LKLL04	40,8	156,0	156,0	621,8	6,84	7,05	0,675	6,181	1,912	-0,244	5,856	2,395
27	LKLL05	51.0	139,2	177,6	624,2	6,84	8,73	0,888	6,712	2,476	-0,322	6,231	2,313
28	LKLL06	61.2	126,0	198,0	624,2	6,80	6.67	0,651	6,588	1,943	-0,170	6,295	3,809
29	LKLL08	32,4	92,4	629,0	629,0	2,63	31.76	0,543	6,458	1,916	-0,145	6,246	2,541
30	LMRM01	10,2	28,8	28,8	669,8	3,80	9.54	0,633	7,079	2,963	-0,137	6,644	0,456
31	LLRL02	20,4	57,6	57,6	654,2	3,15	6.97	0,525	6,683	1,970	0,198	7,050	0,477
32	LLRL04	24,0	67,2	67,2	698,6	2,86	6.96	0,630	6,217	2,142	-0,076	6,000	0,900
33	LHRH07	30,0	160,8	746,4	746,4	11,60	8.56	0,866	7,382	2,845	-0,094	7,125	3,055
34	LHRH06	30,6	186,0	763,4	763,4	11,10	14,40	0,741	7,893	2,819	0,148	8,320	2,480
35	LHRH04	40,8	201,1	762,0	762,2	8,74	9,87	0,688	7,302	2,759	-0,383	6,480	4,000
36	LHRH02	20,4	216,1	742,2	742,2	3,22	6.37	0,003	7,249	2,435	-0,051	7,030	-1,830
37	LGRG01	10,2	39,6	39,6	780,2	2,50	10.07	0,642	6,813	3,164	-0.320	5,880	2,170
38	LFRF01	21,6	76,8	76,8	806,6	1,74	11,03	0,634	7,443	3,094	-0,089	7,070	1,890
39	LERE03	30.6	129,6	129,6	827,0	3,95	9,31	0,704	7,023	2,578	-0,305	6,460	1,000
40	LERE01	10,2	114,0	114,0	841,4	2,09	4,05	0,710	6,075	2,532	-0,271	5,380	0,350
41	LDRD02	20.4	210,1	210,1	932,2	4,46	5,82	0,970	6,575	2,515	-0.122	6,300	2,038
42	LDRD04	40,8	230,5	230,5	924,2	9,60	11,52	0,690	8,293	2,884	0,354	9,200	2,480
43	LDRD06	61.2	258,1	258,1	924,2	11,82	6,54	0,858	7,565	1,819	-0,248	7,070	3,605
44	LDRD08	41.6	284,5	925,4	925,4	13,14	8,37	0,800	6,868	2,430	0,106	7,070	3,055
45	LDRD10	15,6	309,7	930,2	930,2	7,08	58,85	0,514	7,013	2,619	0,262	6,560	2,160
46	SPOTBC	10.8	32,4	32,4	1082,9	3,50	8,60	0.632	6,930	2,765	0.277	6,387	3,552
47	LBRB02	12.4	100,8	100,8	1093,8	7,70	6,54	0,564	7,820	2,613	-0.127	7,015	3,990
48	LCRC01	21.6	63,6	63,6	1092,3	1,75	10,56	0,595	5,246	1,716	-0.562	4,306	0,800
49	LARA04	40.8	147,6	1010,0	1010,0	13,75	6,57	0,941	7,217	2,834	-0,0[illegible]6	7,235	3,055
50	LARA06	40,2	183,6	1089.6	1089,6	7,10	7,71	0,854	7,253	2,856	0.002	7,290	3.055
51	LARA07	30.0	216,0	1068,8	1068,8	4,70	7,83	0,568	7,050	2,678	-0,251	6,600	4,050

PLATE 3 : JAW GRAB USED FOR SEDIMENT SAMPLE COLLECTION.

The samples were stored in sealed polythene sampling bags until needed for the laboratory analysis of grain size and biogenic characteristics.

b. The location of sample points and sample size

The method used for selecting the position of the cross-sections for the sediment survey was the systematic sampling method. The method has been sucessfully adopted by a number of research workers in the past (for example: Fry, 1950; Wood, 1964; Solohub and Klovan, 1970; Allen, 1971; Thomas, Kemp and Lewis, 1972). McCammon (1975) concluded, on the basis of a number of different sediment surveys of lakes, that systematic sampling was the most efficient sampling method even when sedimentary properties of the environment are completely unknown. The same transects that were used for the areal and bottom topography survey were utilized for sediment sampling. The sediment sampling grid was based upon alternate survey sections except that in certain places sampling intensity was increased where significant variations in sedimentary properties was thought likely to occur.

The determination of sample size is a recurrent problem in research. The information needed to test the adequacy of a sample is the very information that the sampling procedure is trying to determine. The problem is especially complex in sedimentology where a single sample of the population contains within it a population of individual grains (often exceeding a million), the characteristics of which are analysed with respect to a variety of descriptive statistics. Statistical tests require the sample to be drawn at random, i.e. every grain collected should have an equal chance of occuring at one part of the sedimentary deposit as another. The process and technicalities of obtaining such a sample of the sediment is obviously impracticable. The generally accepted practice amongst sedimentologists is therefore to collect a number of specimens of contiguous sediment particles and to assume local homogeneity and that the collective characteristics of each sample reflect the overall characteristics of the area sampled. (Blatt, Middleton and Murray, 1972).

It was mentioned earlier that sample intensity was increased in expected zones of sedimentary transition so that a more reliable indication of facies boundaries could be obtained. Figure 22 shows the location of sediment samples chosen for the Howison's Poort reservoir. At the initial stage, 84 samples were collected at 10 m intervals along the cross sections. The exact location of the samples was determined by winching a graded nylon ski rope between the beacons (Plate 4). Subsequent laboratory analysis showed that the properties in the main body of the reservoir showed little variation whereas those in the major inlet showed considerable variation (Table 5).

PLATE 4 : THE EXACT LOCATION OF SAMPLE POINTS DETERMINED BY GRADATIONS ON NYLON ROPE WINCHED ACROSS RESERVOIR CROSS-SECTIONS.

TABLE 5:: VARIATIONS OF MEAN GRAIN SIZE IN THE MAIN BODY OF THE RESERVOIR AS COMPARED WITH THOSE IN THE VICINITY OF THE MAJOR INLET.

	Major Inlet	Main Body
Mean grain size (ø)	2,614	6,535
Extreme phi values	1,78-4,52	4,98-8,29
Area (km^2)	0,003159	0,068791
Area (%)	4,45	95,55
Index of change in ø per km^2	867, 4	48,1

Based on the rapid decrease in grain size observed for the sediments within the vicinity of the major inlet to the reservoir, it was decided to reduce the number of samples analysed in the main body of the reservoir and to retain a high frequency of sample points in the vicinity of the major inlet. The final sample was reduced to 51 by omitting every second sample in the main body of the reservoir (figure 22). In the strict statistical sense, the results obtained from such non-random sampling may not be used for describing the characteristics of the whole area sampled. Therefore, in order to test hypotheses related to sediment distribution in the reservoir as a whole, only samples falling within the uniform grid should be used. The uniform grid is obtained by ignoring alternate samples in the vicinity of the major inlet (i.e. samples 1,3,5 and 7 (Figure 22)). Samples 1,3,5 and 7 are included mainly for comparison and all statistical tests exclude these data points. In all graphs showing the relationship between sedimentary properties, samples 1,3,5 and 7 are marked with a cross (X) so that samples extra to the basic sample grid can be distinguished.

THE LOCATION OF SEDIMENT SAMPLE POINTS IN THE HOWISON'S POORT RESERVOIR

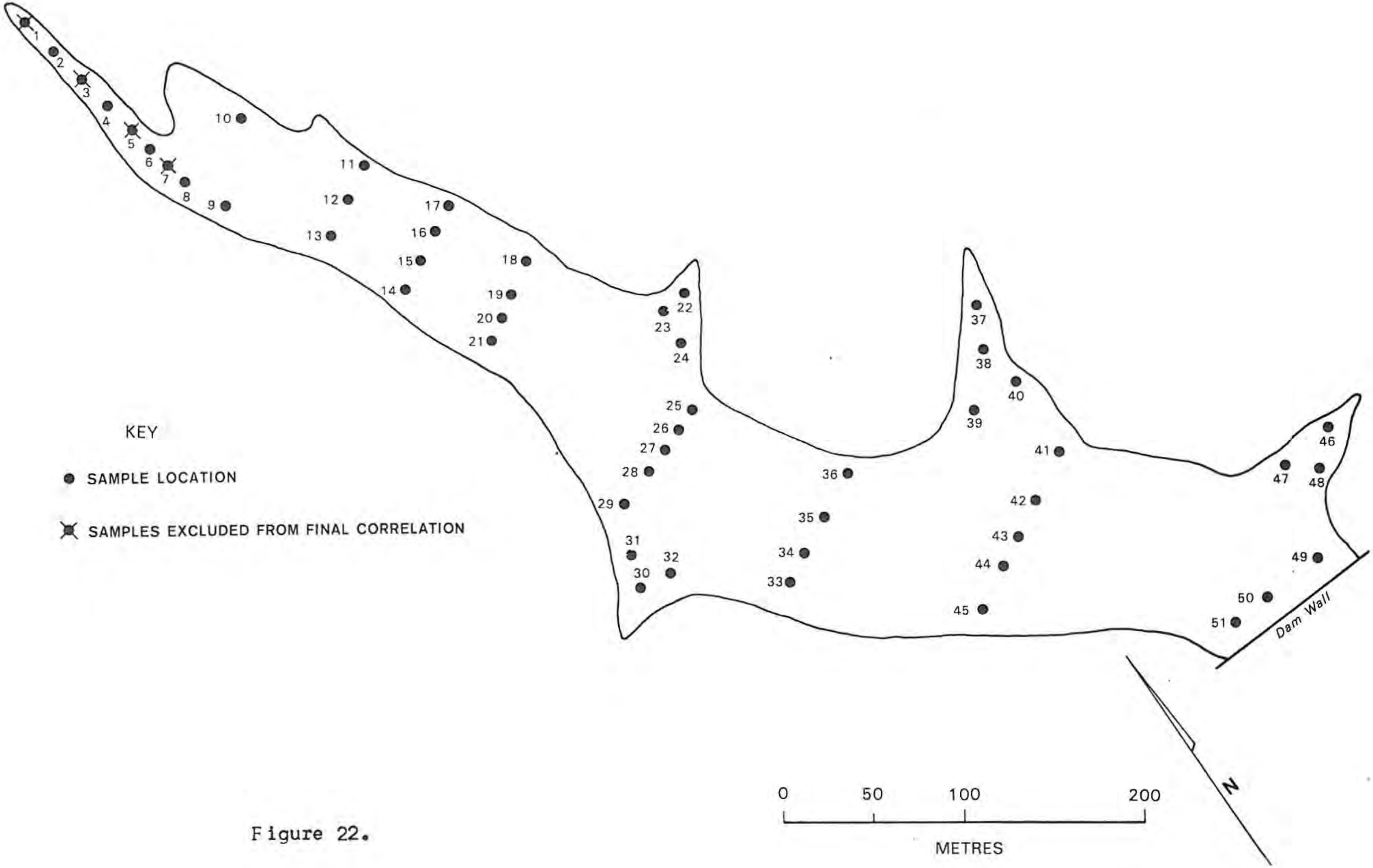


Figure 22.

5.2. Laboratory Data

Data for the distribution of grain sizes and calculation of the proportion of biogenic material in each sample were obtained from laboratory analysis. Full details of the methods used for obtaining this data are listed in appendices A and B. This section discusses the reasons for the choice of analytical technique and considers some of the problems encountered in obtaining the laboratory data.

5.2.1. The determination of the proportion of biogenic matter in the sediment.

The procedure used for the present study is a simple method commonly used by sedimentologists and limnologists and entails the calculation of the weight loss of the sample after ignition at 550°C for four hours. The procedure adhered to was that described by Grant-Gross (1971). The major considerations affecting the choice of method were cost, time and available equipment. Equipment facilitating higher accuracies of measurement, for example, high-temperature combustion furnaces, automatic carbon analyzers, gasometric analyzers and carbon dioxide detectors (Grant-Gross, 1971), were not available to the author. The measurement of weight loss after oxidization with hydrogen peroxide was initially adopted. The method is relatively cheap and rapid, but it was found that samples containing fairly large individual pieces of vegetal matter were not completely oxidized.

A full description of the method used is given in Appendix A. Grant-Gross (1971) describes the method as being simple, rapid and requiring the minimal amount of equipment. Further support for the use of combustion in determining organic content is found in the comparative study of available methods by Dean (1974).

5.2.2. Grain size analysis of the reservoir sediment

The method of measurement of grain size adopted depends largely on the nature of the sample (King, 1966). Sieving is usually used for sizing gravel and sand particles, settling velocity methods for clay and silt particles (Bascomb, 1968). Because of the wide spread of grain sizes in the sediments, it was necessary to use two separate methods of analysis; one for the sand and one for the silt constituents of the sediment sample. Dry sieving was used for the sand and hydrometer analysis was used for the silts. This section discusses the reasons for this choice, the methods employed for the pretreatment of samples and the subsequent grain size analysis. A more detailed description of the procedures involved is presented in Appendix B.

a. Pre-treatment of the sample

Thorough disintergration of the sediment sample into its consitiuent grains is an extremely important initial step in all methods of grain size analysis. The process is especially important with fine grain sediments which tend to adhere to each other by the process of flocculation. Carbonate material also tends to interfere with the dispersal of the sample and must be removed. The removal of carbonate material was effected by adding hydrogen peroxide to the sample (Appendix B.1.) which works as an oxidizing agent on the carbonate material. The deflocculated sediment particles were then maintained in that state by the addition of sodium hexametaphosphate which acts as a peptizer (Galehouse, 1971) (Appendix B.2.). The dispersed sediment was then washed through a 63 micron sieve. The sediment larger than 63 microns was analysed by dry sieving and that finer than 63 microns by hydrometer analysis.

b. Dry sieving

"Sieving remains the preferred method for unconsolidated sands and friable sandstones. It is relatively rapid, trouble free, cheap and the oldest, most tested method." (Pettijohn, Potter and Siever, 1972, p. 70). There is, however, a number of possible shortcomings to a sieve analysis:

i. "It is not exactly clear what property of the grain is measured by sieving. It is certainly not a "pure" size but some compound of size and shape. An approximation is probably the intermediate diameter or some measure of the cross-sectional area of the particle." (Blatt, Middleton and Murray, 1972, p. 47.). For example, long needle-shaped particles will be able to pass through the same mesh as spheres with the same diameter. Only the minimum and intermediate diameters are taken into account. Sieving does not therefore necessarily reflect the average diameter of the sediment (Krumbein and Pettijohn, 1958).

ii. Different time periods of shaking can produce very different results. Particles close to the critical radius will be delayed before passing through the sieve (Krumbein and Pettijohn, 1958). This relationship is summarized by the graph in figure 23.

iii. The size of sieve openings may change with usage (King, 1966).

iv. Density is not considered at all in sieve analysis and sediments with particles of varying densities will produce anomolous results in the weighing section of the procedure.

All of the above mentioned problems can be minimized in the present study in the following ways:

i. Individual inorganic particles were assumed to be spherical. Sediments transported by fluvial processes can be assumed spherical in shape (Pettijohn, 1957; and Blatt, Middleton and Murray, 1972).

ii. Mechanical shaking was allowed for exactly 12 minutes for each sample so that any errors due to incomplete shaking are similar for all samples.

iii. A relatively new set of British Standard sieves was used so that the likelihood of defects was minimal.

iv. A microscope analysis of a number of samples revealed that over 99% of the inorganic sediment particles consisted of quartz grains. The specific density would therefore remain virtually constant for all sediment particles (i.e. 2,65).

c. Hydrometer analysis

The hydrometer method was chosen largely due to the fact that several experiments could be run simultaneously and a minimal amount of specialized equipment was required (Appendix B.4.). "Theoretically the hydrometer measures the density of a suspension at a given depth with time." (Bauer, 1956, p. 75). Day (1953), compared the hydrometer and the more popular pipette methods of grain size analysis and found extremely close agreement between the two techniques.

The method of analysis known as the hydrometer analysis falls under a broad range of grain size analysis techniques known as sedimentation analysis. Sedimentation analysis utilizes the

PROGRESS OF SIEVING ON SIEVE WITH MESHES OF 0,5mm
(Krumbein and Pettijohn, 1958)

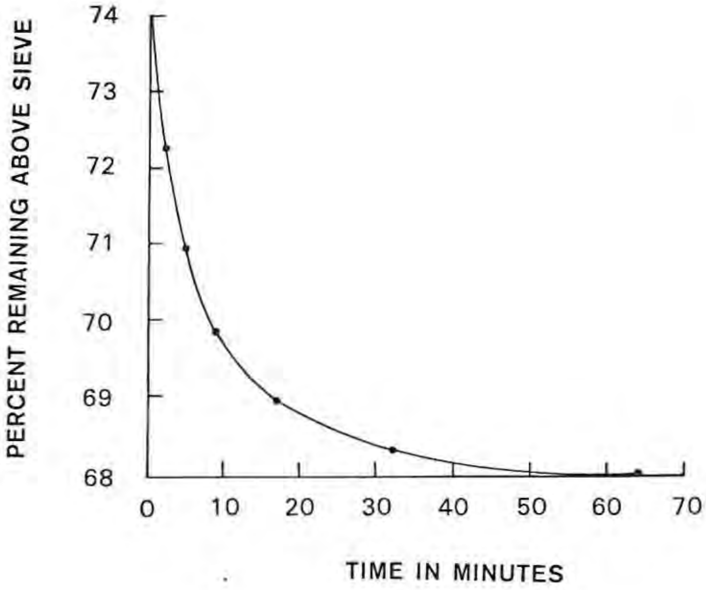


Figure 23.

settling velocity of particles, and, consequently, interpretations concerning sedimentological history based on this measure tend to be more valid than interpretations based on physical size alone (Galehouse, 1971). The principle relied on in sedimentation techniques is that if two particles start falling at the same time, the larger will settle faster than the smaller. The fall or settling velocity of the various grain sizes in the water is conveniently calculated by recording the time of free fall of the particle through a column of motionless water (Modarresi, 1968).

The settling velocity of the particle is transformed to a size scale by means of Stoke's Law:

$V = Cd^2$

Where V= Settling velocity

d= diameter of the particle

C= a constant $\left(\frac{2}{9} \frac{(d_1 - d_2)}{n} g\right)$

Where d_1= density of particle

d_2= density of fluid

g = acceleration of gravity

n = viscosity of fluid

When C is assumed a constant; quartz is assumed to be the main constituent (d_1= 2,65 g per cm^3), water is used as the suspending media (d_2= 1,00 g/cm^3), temperature, pressure and locality are constant (n= 0,01 poise at 20°C and atmospheric pressure), the acceleration of gravity, g= 980 g/cm^2.

Then, $V = \frac{2}{9} \frac{(2{,}65 - 1{,}00)980}{0{,}01} d^2$

Therefore, $V = Cd^2$

Where $C = 3{,}59 \times 10^4$ at 20°C and atmospheric pressure.

Velocity, V, is usually broken into the two components distance and time.

The sedimentation methods used when measuring the size frequency distribution of sediments can be classified into six types:

i. Changes in density of the suspension with time at a given depth;

ii. Changes in density of the suspension with depth at a given time;

iii. Changes in hydrostatic pressure of the suspension with time at a given depth;

iv. Changes in hydrostatic pressure of the suspension with depth at a given time;

v. Changes in weight of an immersed body in the suspension with time at a given depth;

vi. Changes in weight of the sediment deposited from suspension at a given depth. (Bauer, 1956).

Various types of apparatus are available for the calculation of particle size distribution of the sediments using sedimentation techniques and by the application of Stokes' Law. The apparatus available includes pipettes, sedimentation tubes, hydrometers and sedi-graphs.

There is a number of limitations in the application of Stokes' Law in techniques of analysis using sedimentation:

i. Stokes' Law is limited to particles which fall in the 0,5 to 50 micron range.

ii. The downward flow of a particle initiates an upward flow of liquid around it which in turn hinders the settling of adjacent particles (Kuenen, 1968).

iii. Particles tend to settle in clouds at a faster rate than is natural for constituent grains (Kuenen, 1968).

iv. Stokes' Law assumes all particles to be spheres, whereas, in nature, this is seldom the case (Galehouse, 1971).

v. Particles settling near the wall of the cylinder in which measurements are taken are hindered in their settling (Galehouse, 1971).

vi. Particles must be smooth; this is seldom the case in nature (Galehouse, 1971).

Many of the above shortcomings are overcome due to the fact that the sediments analyzed by sedimentation methods are limited to the clay/silt particles and the above mentioned effects are minimal on particles within this range (Galehouse, 1971). In applying Stokes' Law, the actual physical diameter of the particles is not determined, only the sedimentation diameter which reflects the complex interaction between the kinds and proportions of elements, the size of the elements and the shape of the elements is determined (Griffiths, 1967; Galehouse, 1971). This observation is true for all sedimentation techniques and the choice of technique is usually a matter of convenience (Griffiths, 1967).

d. Final report of sediment analysis results

In chapter 2.3.1. it was noted that the concept of size depends on the method used for measurement. Two different methods of measurement were used in the present study; two different "types" of size are therefore combined, grain size inferred from a sieving analysis and grain size inferred from the measurement of the settling velocities of particles.

The use of two different "types" of grain size results in a kink in the curve drawn on the particle size distribution chart (figure 24). This kink has been observed by other workers (for example Griffiths, 1967). In an attempt to smooth the curve, the mean value for the amount of sediment passing the 63 micron sieve and the percentage of sediment finer than 63 microns recorded in the hydrometer analysis was taken. This method does not convert all the values of measurement on the one section of the curve to equivalent values on the other. Nevertheless, it is a method which has been used consistently throughout the study which is primarily concerned with relative differences in particle size distribution of the various samples and not absolute values for any one particular sediment sample. The grain size parameters needed for the study were calculated using a FORTRAN computer program (Gilson, 1977) (Appendix C.1.). When compared to manually calculated values for the grain size parameters the above method shows an error of 0,03 ∅ and usually less. This error is small enough to be of no influence. Where sediments were analysed using both sieving and hydrometer methods, the data input was in the form of percent material retained per sieve phi size.

TWO SEGMENTS OF THE SEDIMENT DISTRIBUTION CURVE OBTAINED USING SIEVING AND HYDROMETER ANALYSIS AND THE CORRECTED SEGMENT OF THE CURVE

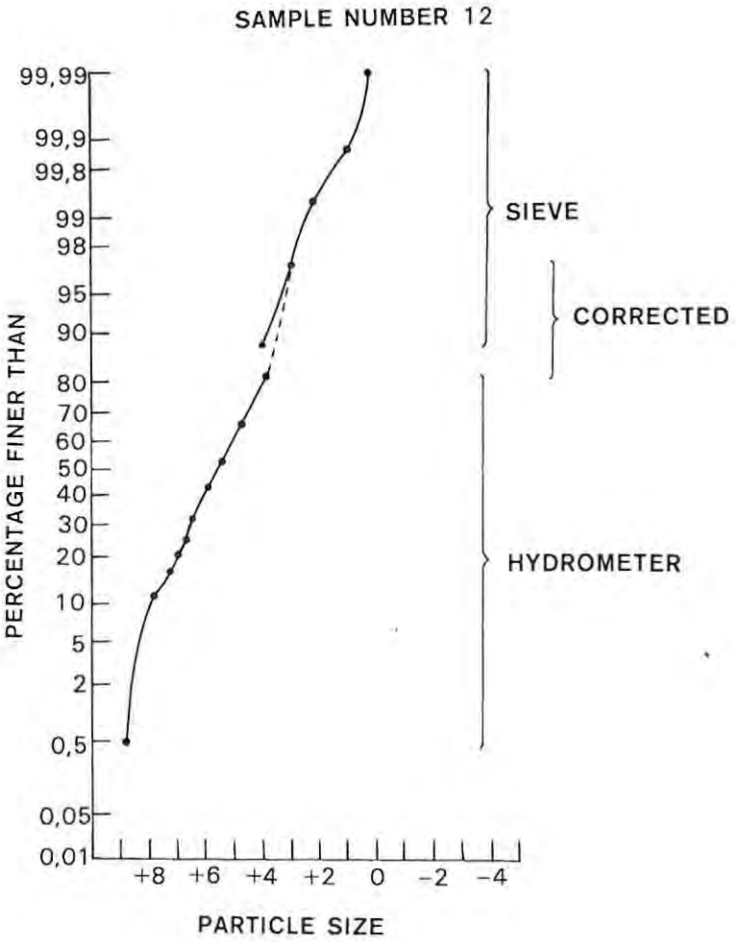


Figure 24.

(Appendix C.2.). Where only sieves were used, the input consisted of weights retained per sieve phi size. (Appendix C.3.). All of the data derived from laboratory analysis and field survey used in the testing of the hypotheses is listed in Table 4.

In the chapter that follows, Chapter 6, the data collected is used to verify the hypotheses formulated in chapter 4.

CHAPTER 6

EVALUATION OF THE HYPOTHESES AND DISCUSSION OF THE RESULTS

In chapter 4 the study hypotheses were proposed. The hypotheses were framed around the theoretical concepts outlined in chapter 2. In chapter 5 the collection of data necessary for the verification of the study hypotheses was discussed. The purpose of this present chapter is to examine each of the study hypotheses independently with respect to selected environmental and sedimentological parameters. The hypotheses are considered with particular reference to the theoretical background which initiated their formulation. An outline of the methodological framework within which the hypotheses are tested is presented at the outset of this chapter. Four broad aspects of the spatial variation of sediment form the framework of the subsequent sections of this chapter; 1) distribution of inorganic sediment, 2) identification of subenvironments of deposition, 3) distribution of biogenic material and 4), the relationship between selected grain size parameters and the proportion of biogenic material.

6.1. Methodology

The procedure followed for testing the hypotheses is based on the scientific method discussed elsewhere by numerous workers (for example: Griffiths, 1967; Davis, 1973 and Norcliffe, 1977). Statistical tests are used to substantiate the existence and strength of spatial variations in selected sedimentary properties of the Howison's Poort reservoir sediments.

Correlation analysis is used to test the strength of the relationship between sediment characteristics and spatial location. Because of the large volume of data, a computer package developed by Davis (1973) was used. The program is especially designed for geological data where one variable (X) is spatially defined and the other (Y) is distributed along this continuum. The program (CORE) is listed in appendix D. The program calculates the regression line so that the sum of the squared distances from the observed points to the fitted regression line is minimized. The "goodness of fit" and the correlation coefficient of the regression line are calculated. The correlation reflects the "... degree to which changes in one direction and magnitude in one set of data are associated with comparable changes in the other set" (Gregory, 1963, p. 189).

The acceptance or rejection of the hypotheses is based on criterion suggested by Davis (1973). The study hypothesis (H_1) and its converse, the null hypothesis (H_o) are both considered. The hypotheses are either accepted or rejected on the basis of the statistical tests employed. The null hypothesis is formulated with the intention of being rejected; thus minimizing the possibility of committing a type II error (β) (i.e. that an incorrect hypothesis is accepted). A significance level of 95% is selected (the most commonly used level by geologists (Davis, 1973)) so that there is a 5% (maximum) chance of committing a type one error (α) (i.e. that a correct hypothesis is rejected). The significance test used in the study is the Students' t-test (a complete description of this method is given in appendix D).

The routine of testing the hypotheses (discussed above) is merely a tool used to test the strength of the relationship between selected variables. The result of statistical tests are not in themselves conclusive; all results must be carefully considered with respect to both the theoretical framework and the broad aspects of the theoretical background. The existence of a correlation between two variables does not necessarily mean that these two variables exhibit a cause and effect relationship; there is always the possibility of other links (Ward, 1978).

The results of the statistical routines described above are tabulated in table 6. The following section considers the results obtained from the application of statistical routine to study data with reference to

TABLE 6 : SUMMARY OF THE RESULTS OBTAINED FROM THE STATISTICAL ANALYSIS OF THE HYPOTHESES.

Hypothesis number	Sample size (n)	Degrees of Freedom (-2)	Goodness of Fit (R^2)	Goodness of Fit (%)	Correlation Coefficient (R)	Student's t-test (t)	Level of significance (%)	Hypothesis Accepted	Hypothesis Rejected
1 a	47	45	0,187	18,7	0,433	3,573	99,99	H_1	HO
1 b	47	45	0,082	8,2	0,287	2,009	95	H_1	HO
1 c	47	45	0,632	63,2	0,795	8,786	99,9	H_1	HO
1 d	47	45	0,323	32,3	0,571	4,653	99,9	H_1	HO
2*	47	45	0,759	75,9	0,871	11,900	99,9	H_1	HO
3 a	44	42	0,068	6,8	0,260	1,808	90	HO	H_I
3 b	44	42	0,020	2,0	0,142	0,930	80	HO	H_1
3 c	44	42	0,261	26,1	0,511	3,851	99,9	H_1	HO
3 d	44	42	0,082	8,2	0,286	1,935	90	HO	H_1
4 a	44	42	0,453	45,3	0,673	5,900	99,9	H_1	HO
4 b	44	42	,384	38,4	0,620	6,520	99,9	H_1	HO

* (So vs Mz)

environmental and sedimentological information obtained from the survey and with reference to the theoretical framework to the study.

6.2. The Distribution of Inorganic Sediment.

6.2.1. Hypothesis 1(a):

"There is an inverse relationship between the distance from the nearest reservoir bank and the mean grain size of inorganic sediment".

The two variables used to determine the validity of the hypothesis were mean grain size (Y_{mz}), the dependent variable, and distance from the nearest reservoir bank (X_{DB}), the independent variable. Folk and Ward measures were used to calculate the mean grain size parameters. From the known position of the sediment sample, the distance to the nearest reservoir bank was measured in metres (Table 4, columns 3 and 7).

Because the individual cross-sections contained too few data points, a single graph of data from all sections was drawn (figure 25). Distance values are represented logarithmically in the graph so that a clearer visual impression of the relationship can be obtained. Distance from the nearest bank is shown to explain 18,7% of the variance in mean grain size of the reservoir sediment. The relationship holds true within the level of significance set for the study. The null hypothesis is therefore rejected on these grounds and the study hypothesis is accepted.

The explanation of grain size variance by nearest bank distance values can be attributed to the effects of turbulence produced by wind and temperature in the epilimnion of the reservoir water body (chapter 2.1.2.). It is, however, likely that sediment input and hence distance of transport is also related to fluvial

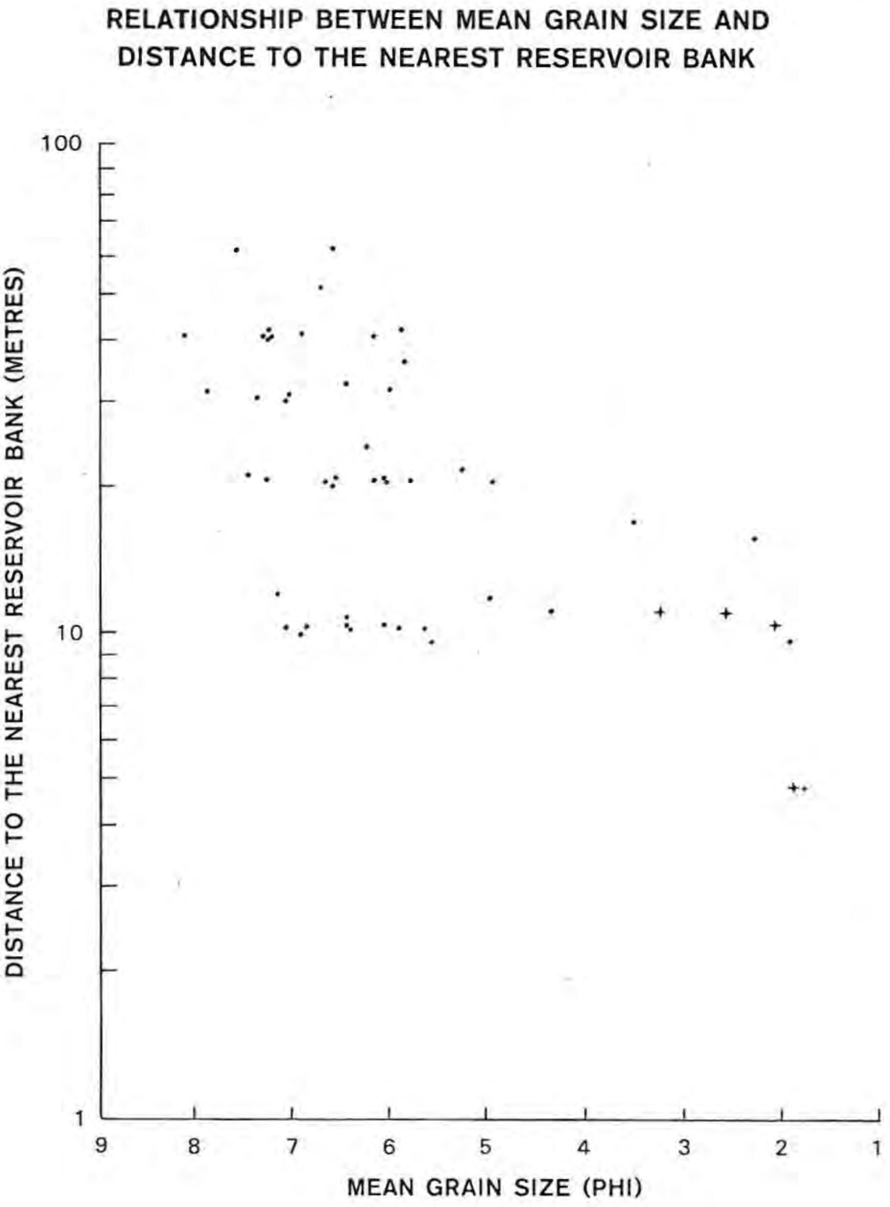


Figure 25.

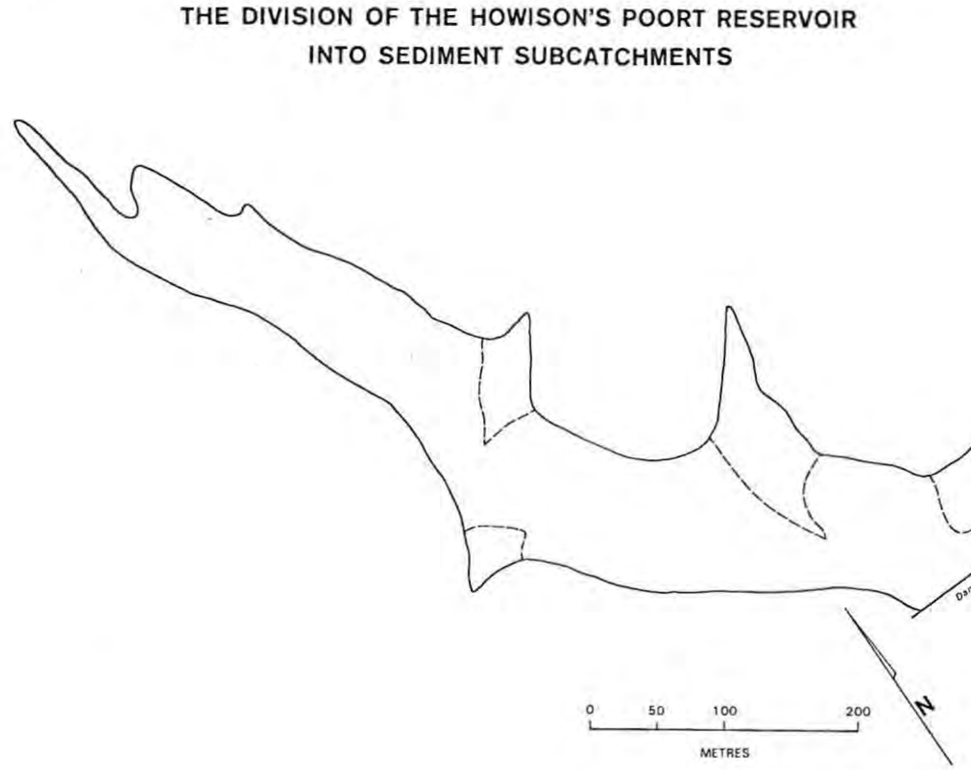
energy of tributary streams. For this reason the next hypothesis is considered and an examination is made of the amount of variance in mean grain size explained by the distance from the sampling point to the nearest reservoir tributary.

6.2.2. Hypothesis 1(b).

"There is an inverse relationship between the distance to the nearest reservoir tributary and the mean grain size of the inorganic sediment".

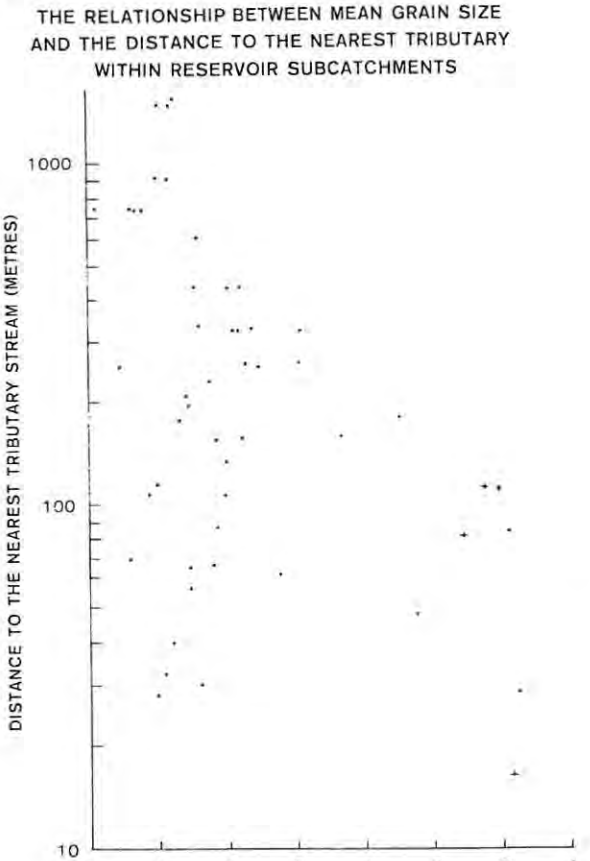
The mean grain size of the sediment (Y_{mz}) was assumed to be the dependent variable and distance from the nearest reservoir tributary (X_{DT}) was assumed to be the independent variable. Folk and Ward measures were used to calculate the mean grain size (phi). From the known positions of the sediment samples, the distance to the nearest tributary stream was measured (metres). The point of entry of the tributary streams was taken as the point where the stream crossed the "0" depth contour in figure 21. The data used for testing the hypothesis is tabulated in table 4, columns 4, 5 and 7. The distances were initially measured as the straight line distances to the nearest tributary stream (table 4, column 4). The percentage of variance in mean grain size explained using this measure was however extremely low (4,1%). The direct distance to the nearest tributary is not, however, a true reflection of the hydraulic distance that the sediment is likely to travel assuming that the point of entry of the sediment is via the tributary streams. It was therefore decided to divide the reservoir up into sedimentary sub-catchments (figure 26) and to measure the distance between the sample point and the point of entry of the stream to the sediment sub-catchment containing that sample (Table 4 columns 5 and 7). The relationship between the two variables is shown in figure 27. The test statistics (table 6), show an acceptance of the hypothesis at the 99% level of significance. 8,2% of the variation in mean grain size is accounted for by variations in the distance from the nearest tributary stream within reservoir sub-catchments.

The fairly low correlation obtained using data from all tributary streams is probably explained by the volumetric domination of the main stream in terms of sediment input and energy. No flow into the



THE DIVISION OF THE HOWISON'S POORT RESERVOIR INTO SEDIMENT SUBCATCHMENTS

Figure 26.



THE RELATIONSHIP BETWEEN MEAN GRAIN SIZE AND THE DISTANCE TO THE NEAREST TRIBUTARY WITHIN RESERVOIR SUBCATCHMENTS

Figure 27.

reservoir was contributed from tributaries during the study period and the tributary channels show no indications of recent flow events. For this reason the distribution of mean grain size of the sediment was considered with respect to the distance of the sediment sample points from the point of entry of the main stream.

6.2.3. Hypothesis 1(c).

"There is an inverse relationship between the distance from the main tributary and the mean grain size of inorganic sediment".

The mean grain size of the inorganic sediment (Y_{mz}) was assumed to be the dependent variable, and distance from the main stream (X_{DM}) was assumed to be the independent variable. Folk and Ward measures were used to calculate the mean grain size (phi units) (table 4, column 10). The distance to the main stream was measured as the straight line distance between the known position of the sediment sample location and the point of entry of the main stream into the reservoir. The point of entry of the main stream into the reservoir was taken as the point where the main stream crosses the "0" contour line (figure 21) (table 4, column 6).

The relationship between these two variables is shown in figure 28. Distance from the main stream is plotted on a logarithmic scale and mean grain size on an arithmetic scale so that a clear visual appreciation of the data can be had. The study hypothesis is accepted and the null hypothesis is rejected on the basis of the statistical tests shown in table 6. 63,2% of the variation in mean grain size, can be accounted for by variation in distance from the main tributary stream.

From the testing of the hypotheses related to bank distance, tributary distance and main stream distance it appears likely that the main

THE RELATIONSHIP BETWEEN THE DISTANCE FROM THE MAIN TRIBUTARY AND THE MEAN GRAIN SIZE OF INORGANIC SEDIMENT

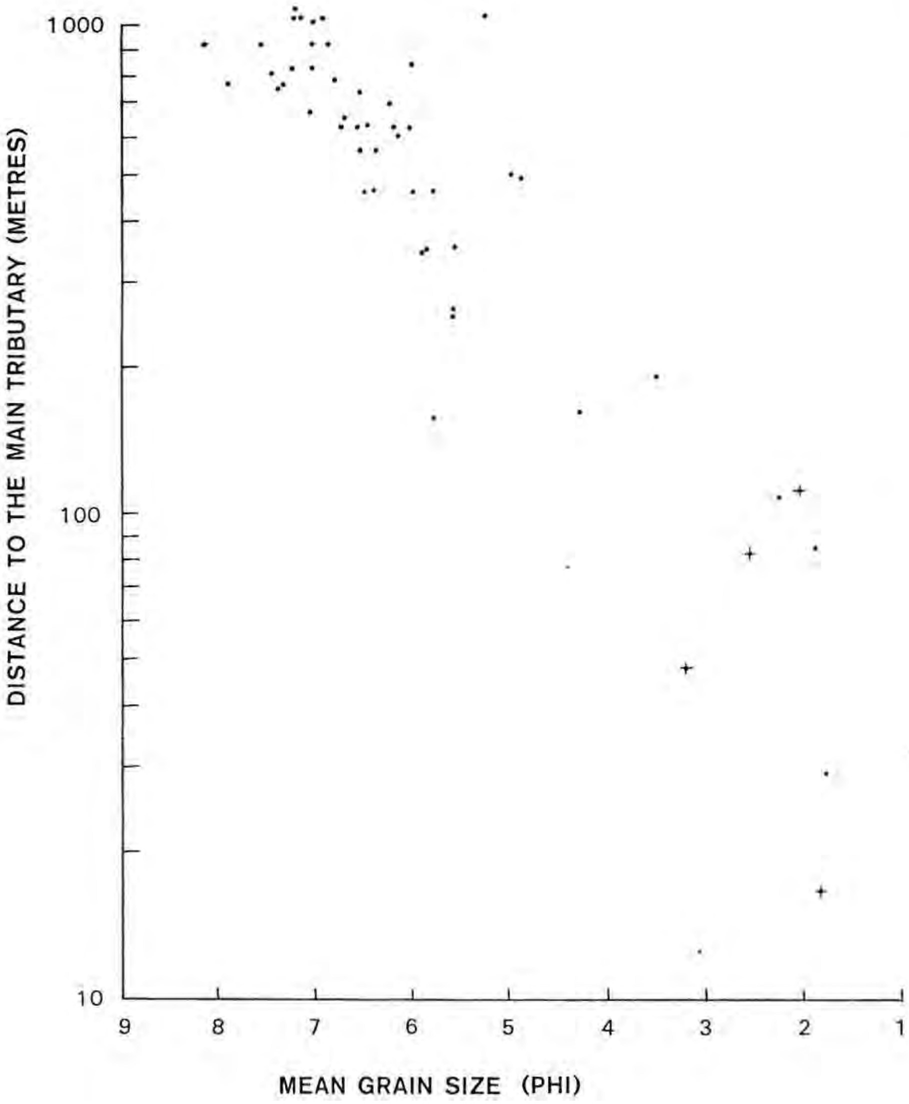


Figure 28.

tributary contributes the majority of the sediment to the reservoir and that the mean grain size of a sediment sample is inversely related to its distance from the point of entry of the main inlet. A further geometrical dimension of a reservoir is water depth and hypothesis 1(d) examines the relationship between the mean grain size of a sediment sample and the depth from which it was obtained.

6.2.4. Hypothesis 1(d).

"There is an inverse relationship between the water depth and the mean grain size of the inorganic sediment".

The mean grain size of the sediment (Y_{mz}) was assumed to be the dependent variable and the depth of the water at the sample location was assumed to be the independent variable (X_{DW}). Folk and Ward measures were used to calculate the mean grain size (phi units). The depth of the water was measured at the time of the reservoir survey (Chapter 5.1.1.). The data used for the testing of the hypothesis is listed in table 4, columns 7 and 10.

The two variables are plotted with mean grain size of sediment on an arithmetic scale and depth of water on a logarithmic scale (figure 29). On the basis of the test statistics (table 6), the

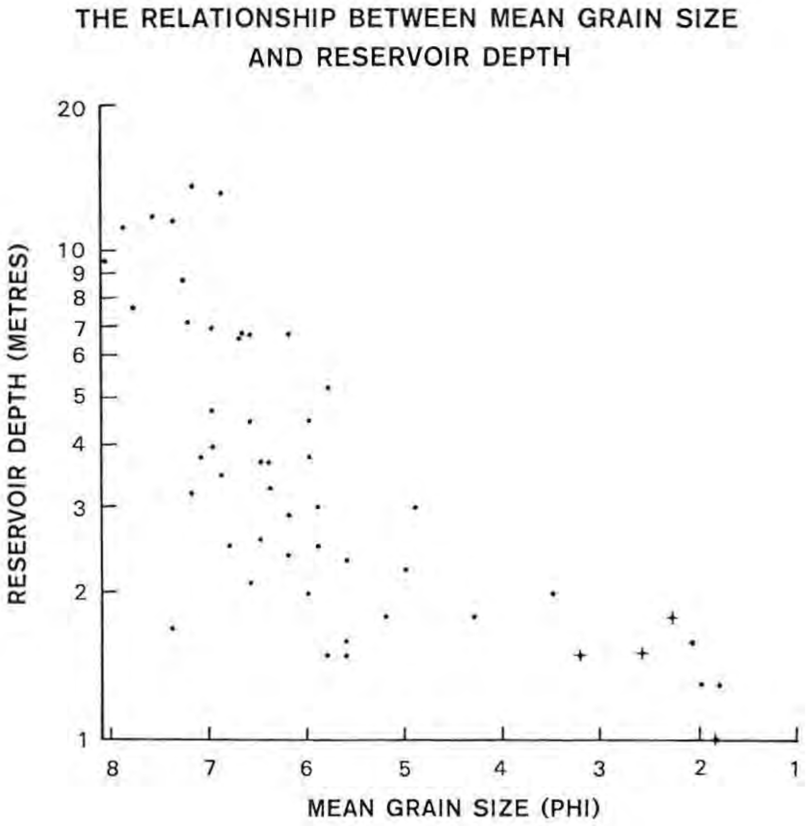


Figure 29.

study hypothesis is accepted and the null hypothesis rejected at the 99,9% level of significance. 32,3% of the variation in mean grain size of the inorganic sediment is explained by variations in reservoir depth. It must be pointed out that there is also a general correlation between reservoir depth and distance from the main tributary. The sedimentological significance of depth and mean grain size of the sediment is considered in greater detail in the following section.

6.2.5. Discussion of the results obtained for hypotheses 1(a), (b), (c) and (d).

Hypotheses 1 (a), (b), (c) and (d) are based on the research findings which suggested that the mean grain size of inorganic reservoir sediment would decrease with distance from their point of input and with decreasing energy conditions. On the basis of the statistical tests, all of the above hypotheses were accepted. The sources of inorganic sediment and areas of relatively high energy conditions in the Howison's Poort reservoir include the reservoir banks, the tributary streams, the main tributary streams and the shallow water areas.

Figure 30 illustrates the generalised distribution of the surficial inorganic sediment types in the Howison's Poort reservoir. The classifications used in the figure are based on the Udden-Wentworth-Lane size classes (chapter 2.3.). The marginal effects of wind and thermally induced currents, discussed in chapter 2.1.2., appear to affect the sediments in the south eastern and the north eastern sectors of the reservoir only. The limited extent of these marginal sediments is probably due to the fact that the reservoir is fairly well protected from winds in the northern section of the reservoir. The effects of epilimnetic turbulence discussed in chapter 2.1.2., will, therefore,

SPATIAL VARIATION IN MEAN SIZE OF OF INORGANIC SURFICIAL SEDIMENT OF THE HOWISON'S POORT RESERVOIR

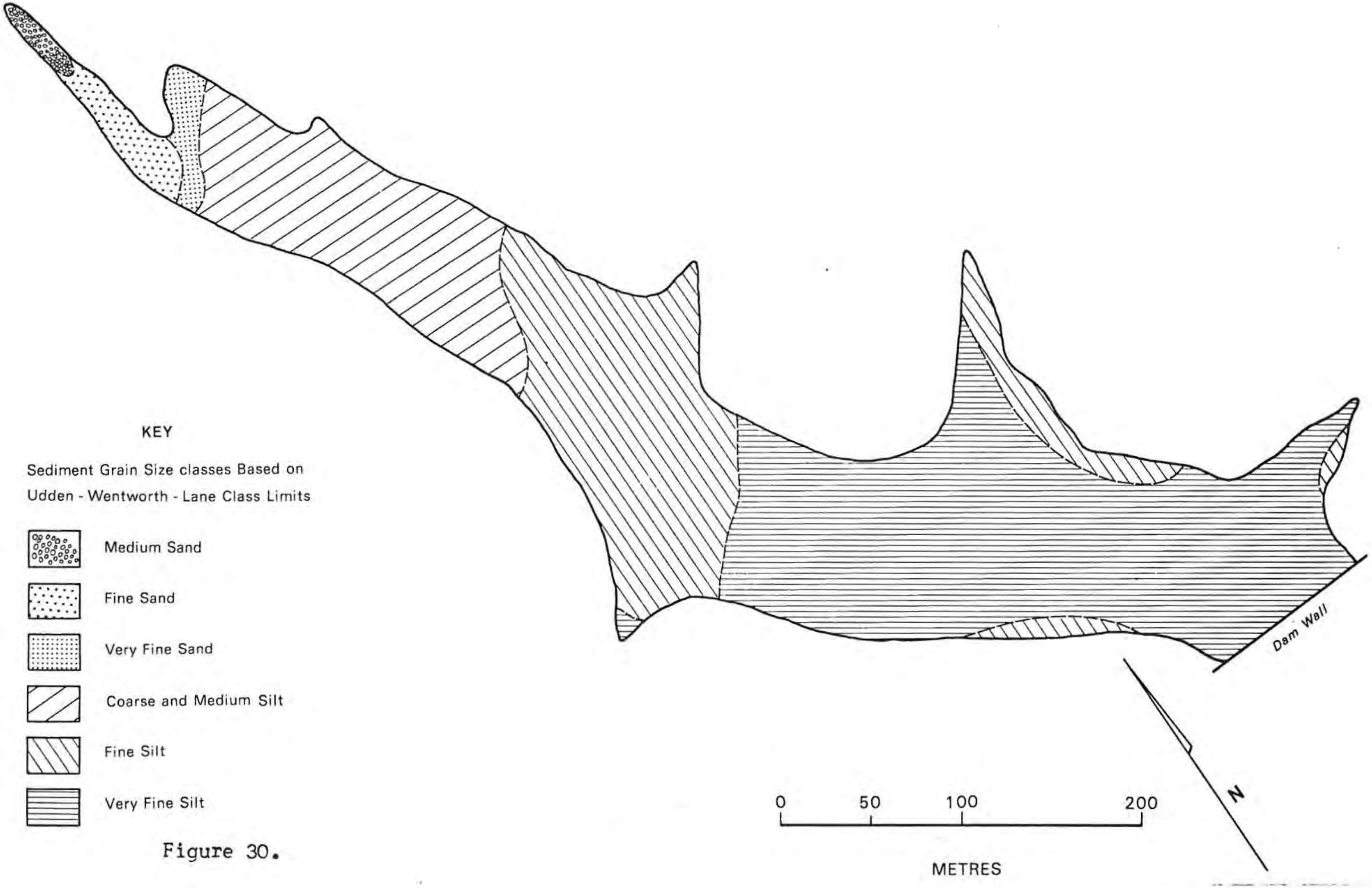


Figure 30.

be confined to the south eastern and north eastern marginal areas.

In reservoirs with gently sloping banks, well developed thermoclines and exposed to strong winds, it is likely that these marginal sediments will be more extensive.

The role of the tributary streams as sources of inorganic sediment and as regions of relatively high energy conditions is limited as was expected (chapter 4.2.). In reservoirs with tributary streams with catchments of comparable area, it is conceivable that there will be a stronger relationship between the areal distribution of the various sediment size classes and the location of the tributary streams.

In the discussion of hypothesis 1 (d), it was pointed out that the correlation between mean grain size and depth of water might represent a spurious correlation because of the strong relationship between depth of water and distance from the main tributary. The geometrical properties of the Howison's Poort reservoir provide for an increase in width and depth with progressive distance from the point of entry of the main stream (figure 21). There is areally a greater amount of deep water near the dam wall than near the point of entry of the main stream. In the case of the Howison's Poort reservoir explanations of sedimentation based upon depth only must be treated with caution. It is, however, true to say that in the Howison's Poort reservoir the mean grain size of the inorganic sediment decreases regularly with a combined increase in depth and distance from the point of entry of the main stream.

As the relationship between the distance from the point of entry and the mean grain size of the inorganic sediment shows a stronger correlation than the other 3 variables selected, it warrants more detailed discussion. Referring to figure 30 it can be noted that there is a relatively rapid transition in mean grain size within the first 250 metres from the point of entry of the main stream and then a gradual decrease in mean grain size in the remaining 800 metres of the reservoir.

In chapter 2.1.1., deposition of reservoir sediment was discussed. In figure 8 and the accompanying discussion it was shown theoretically that velocity of water movement decreased relative to the distance from the point of entry, i.e.

$$V \propto \frac{1}{d} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(i)}$$

where: V= velocity of flow

d= distance from the point of entry

$\propto$= is proportional to.

Stokes' Law of settling velocities of fine particles and Newton's Impact law of settling velocities of coarser particles were discussed in chapter 2.1.1. It was shown that particles within the Stokes' range of settling diameters remain in suspension longer than those within the range described by the Impact Law and that there tends to be an intermediate time intermediate particle sizes (figure 5). On theoretical grounds it appears likely that deposition of the coarser sediment particles in the upper reaches of the reservoir would exhibit characteristics of the Impact Law (or the intermediate stage) (figure 5), whereas those settling in the lower reaches of the reservoir will exhibit characteristics of Stokes' Law.

The algebraic form of Stokes' Law and the Impact Law (discussed more fully in Chapter 2.1.1.) are:

$$V = Cr^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Stokes Law (ii)}$$

$$V^2 = Cr \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Impact Law (iii).}$$

Assuming the constant C to be similar throughout the reservoir, the two laws can be re-written in the form:

$r^2 \propto V$ .... Stokes' law (iv)

$V \propto \sqrt{r}$ .... Impact law (v)

Substituting (i); for conditions in the lower reaches of the reservoir:

$r^2 \propto \frac{1}{d}$ .... Stokes' law (vi)

and in the upper reaches:

$\sqrt{r} \propto \frac{1}{d}$ .... Impact law (vii)

Figure 31 illustrates the relationship between the distance from the point of entry of the main stream and the mean value of the mean grain sizes for each cross section (the line is arbitrarily drawn). The steep slope of section A of the graph and the levelling out in section C of the graph co-incide with the observation made from figure 30 that there is a rapid decrease in mean grain size over the first 250 metres, followed by a more gradual decrease over the remaining 800 metres.

Assuming that equations vi and vii adequately describe the sediment settling mechanisms at either end of the reservoir, then it is clear that any model of reservoir sedimentation must combine the mechanisms of the two laws. If the relationships described by either of the laws is plotted independently using the data for the Howison's Poort reservoir (figure 32 and 33), either of the laws separately fail to account for the sedimentation patterns at one end or the other and kinks are produced in the curves. There is, therefore, sufficient justification on the basis of the theory and the evidence produced that sediment settling mechanisms within reservoirs must be considered in terms of both laws of settling.

The validation of hypotheses 1 (a), (b), (c) and (d) has shown that reservoir sediments are not randomly distributed and that patterns

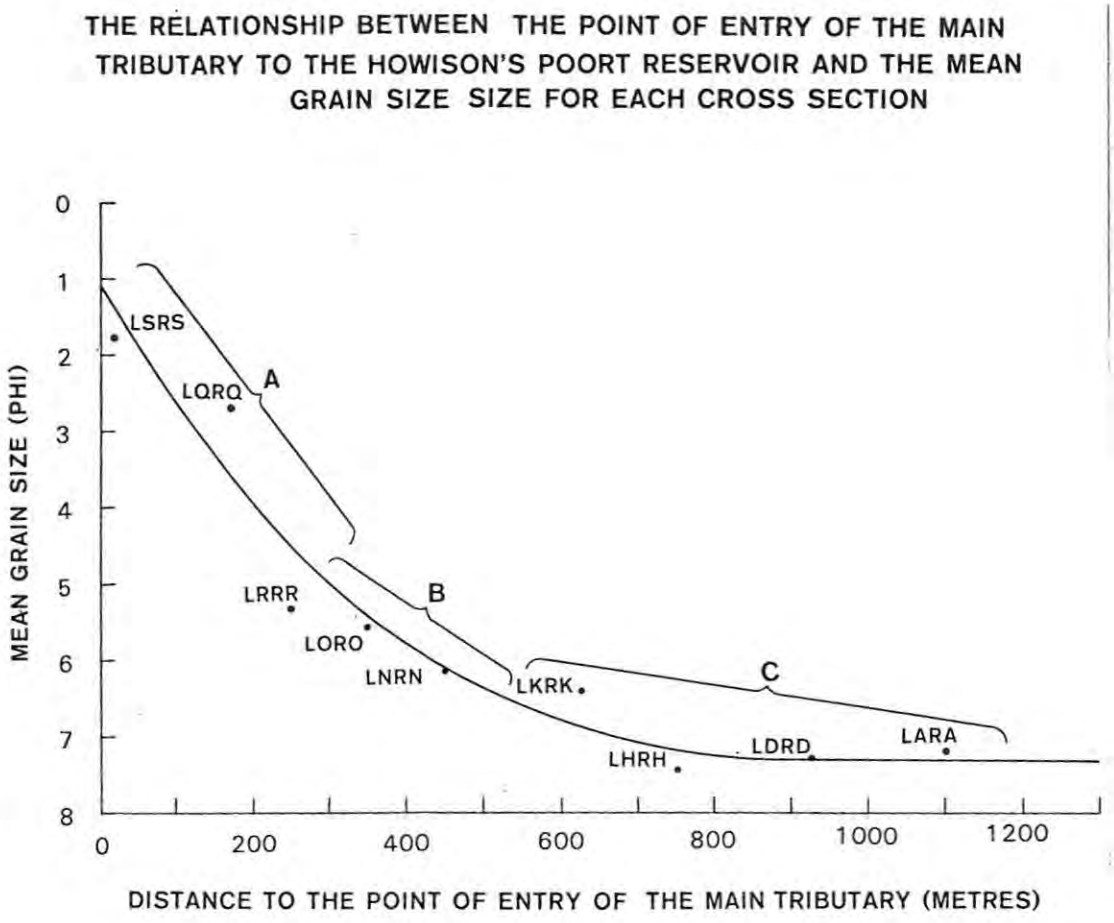

THE RELATIONSHIP BETWEEN THE POINT OF ENTRY OF THE MAIN TRIBUTARY TO THE HOWISON'S POORT RESERVOIR AND THE MEAN GRAIN SIZE SIZE FOR EACH CROSS SECTION

Figure 31.

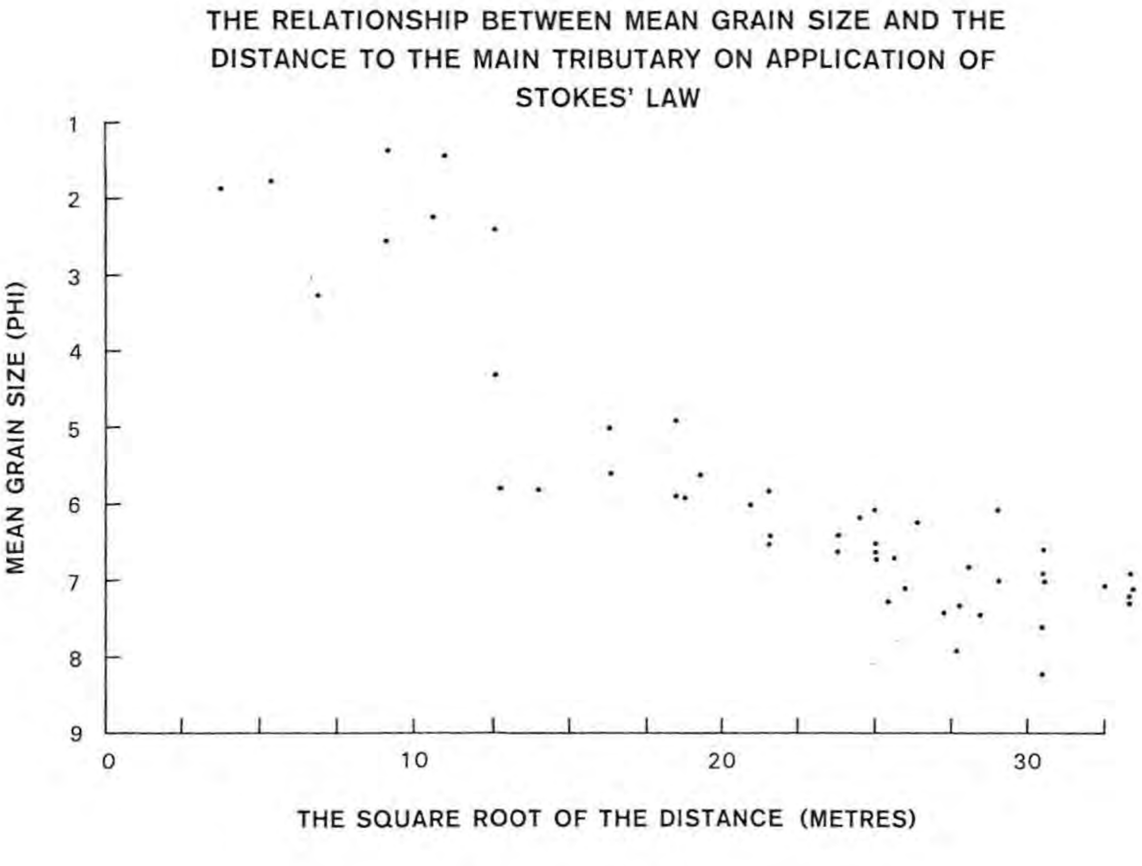

THE RELATIONSHIP BETWEEN MEAN GRAIN SIZE AND THE DISTANCE TO THE MAIN TRIBUTARY ON APPLICATION OF STOKES' LAW

Figure 32.

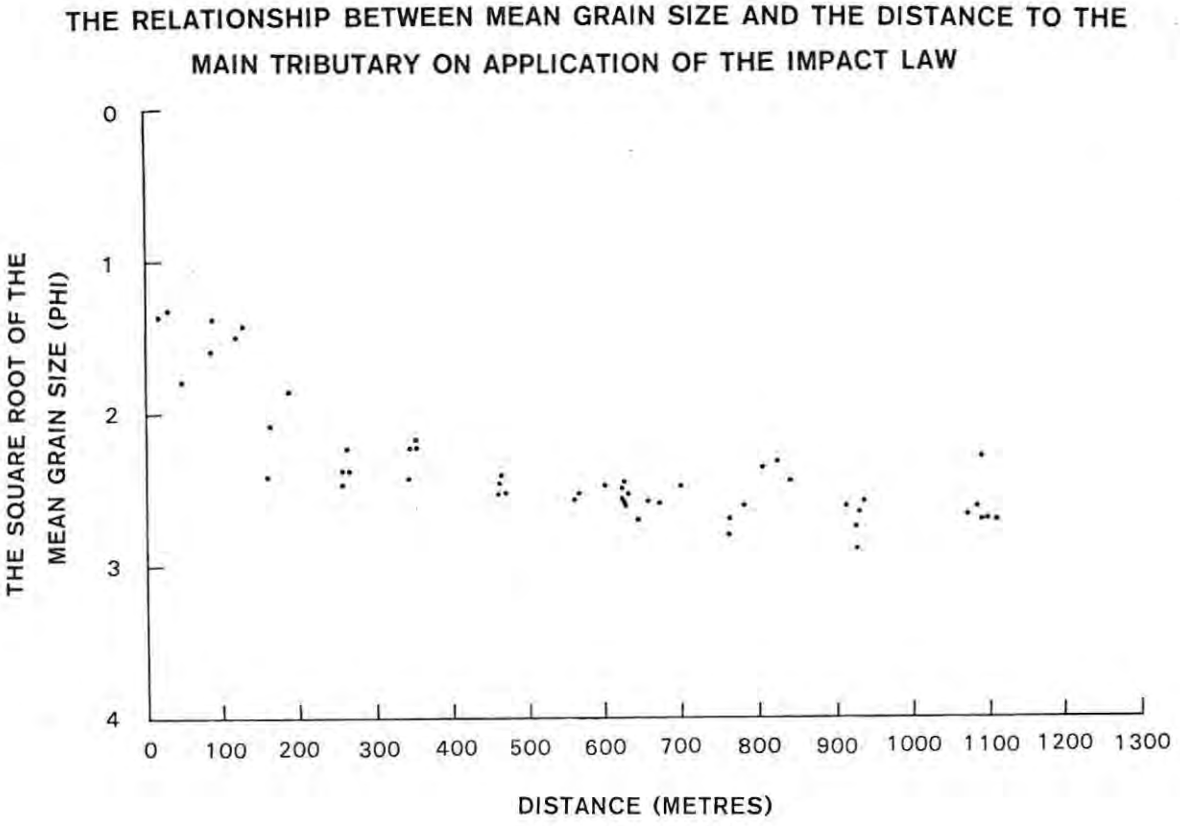


Figure 33.

of grain size distribution can be explained in terms of the theoretical distribution of energy throughout the reservoir. The physical properties of the reservoir most potent in explaining the distribution of sediment sizes in the Howison's Poort reservoir are (in ascending order of importance) the distance to the nearest tributary stream, the distance to the nearest reservoir bank, the depth of the water and the distance to the point of entry of the main stream.

The present group of hypotheses considered mean grain size of sediment samples with respect to distance and depth measurements within the reservoir. The second hypothesis, which is discussed at some length in the section that follows, considers in more detail the textural properties of the inorganic fraction of the sediment samples.

6.3. Identification of Sub-Environments of Deposition.

6.3.1. Hypothesis 2.

"There exist two groups of sediment exhibiting distinctive textural characteristics".

Three different procedures are adopted in the testing of this hypothesis. The purpose of using three different procedures is firstly to serve as a check in assessing the validity of the hypothesis and secondly to establish which of the three procedures provides the most useful method for the differentiation of sediment types.

The three procedures adopted are:

a) a graphical comparison for the sediment samples of their skewness and sorting values, plotted on a scattergram (described by Friedman, 1961, 1967);

b) a graphical comparison of the sorting and mean grain size values for the samples (described by Stewart, 1958 and King, 1966);

c) a graphical representation of the C.M. patterns for the sediment samples (described by Passega, 1957, 1964).

The descriptive moments used in these three procedures are discussed in more detail in chapter 2.

a) Skewness versus sorting

The skewness versus sorting scattergram for the Howison's Poort sediments is shown in figure 34. The most noticeable feature of the graph is that 85% of the samples are negatively skewed, i.e. they have a greater proportion by dry weight of fine material than of coarse material. It can further be noted that approximately 80% of the samples exhibit sorting values of greater than 1,5 (i.e. poorly to very poorly sorted).

SCATTERGRAM PLOTTING THE SORTING AND SKEWNESS VALUES FOR THE HOWISON'S POORT RESERVOIR

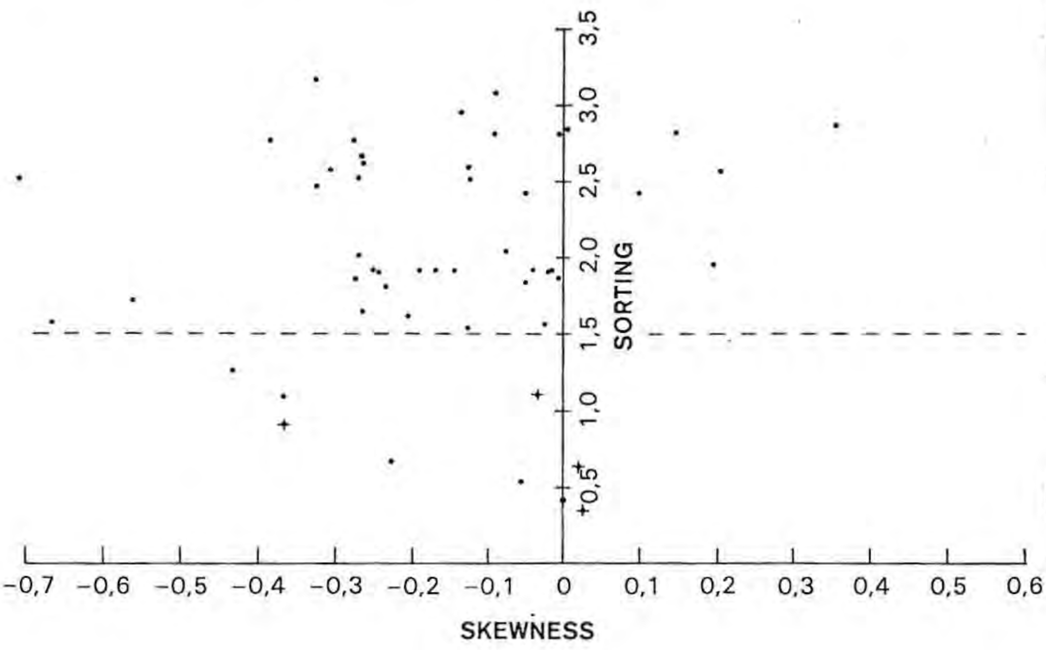


Figure 34.

SCATTERGRAM PLOTTING SORTING AND SKEWNESS VALUES FOR RIVER SAND, BEACH SAND (OCEANS), BEACH SAND(LAKES) (Friedman, 1961); LAKE DEPOSITS (Thomas, Kemp and Lewis, 1972) AND HOWISON'S POORT RESERVOIR DEPOSITS

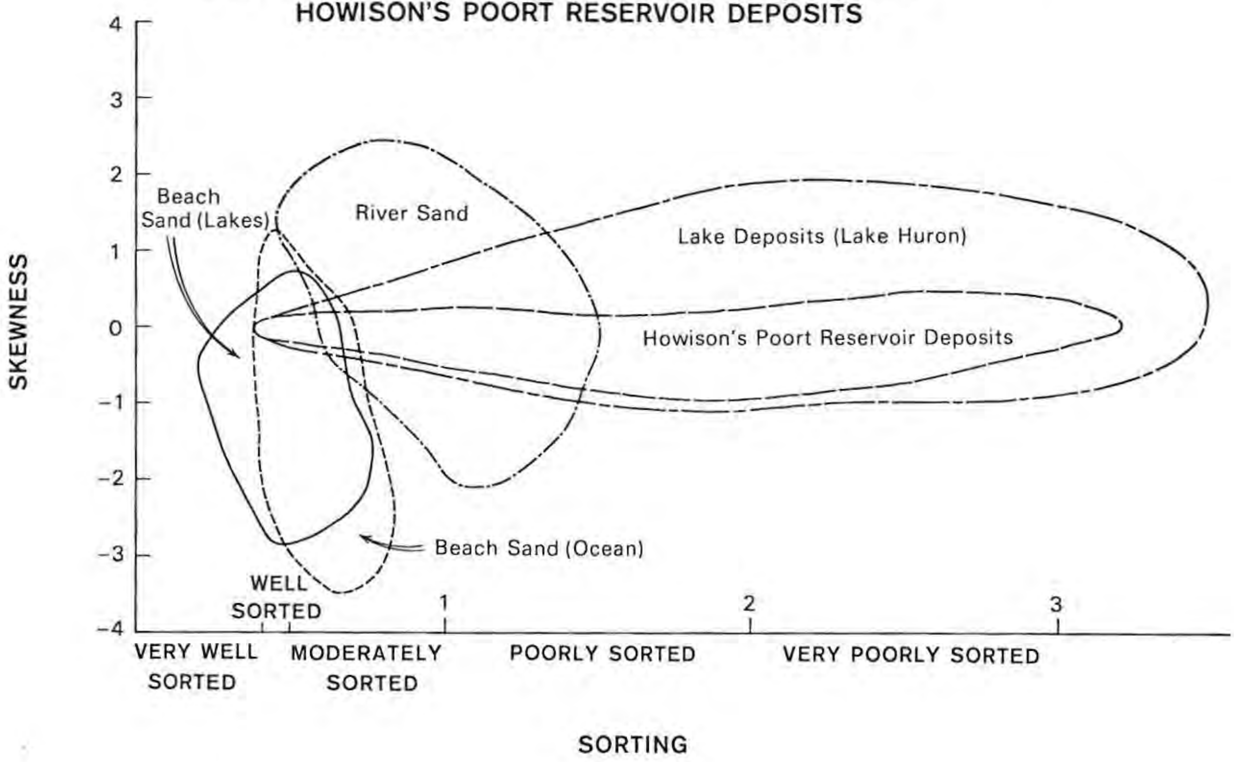


Figure 35.

An arbitrary delineation drawn through the sorting value of 1,5 parallel to the skewness axis delineates the widely scattered points with sorting values below 1,5 from the more tightly clustered points above the line. The nine points below the delineation include samples 1 to 9. Referring to figure 22 it can be noted that these nine points are the samples which occur proximal to the point of entry of the main stream and are, therefore, most likely to be deltaic - type deposits.

In figure 35 the distribution of the skewness/sorting values for Lake Huron (Thomas, Kemp and Lewis, 1972) and those shown in figure 34 are added to the scattergram drawn by Friedman (1961) (see figure 17 in chapter 2.3.5.). A comparison of the graphical position of the Howison's Poort data with the position occupied by Lake Huron deposits and those plotted by Friedman (1961) may provide further insight to the sedimentological environments of the study area. Howison's Poort reservoir sediments have a wider variation in sorting values but a narrower variation in skewness values than do the deposits plotted by Friedman (1961). Reservoir sediments with sorting values greater than 1,5 intercept with Lake Huron deposits only; whereas sediments with values lower than 1,5 intercept with values obtained for lake deposits, river sands, ocean beach sands and lake beach sands. The environments plotted by Friedman (1961) are all examples of relatively high energy environments which are good sorting agents. Lakes and reservoirs are subject to deposition under both relatively high and relatively low energy conditions. The delineation of the reservoir and lake deposits at their point of interception with deposits described by Friedman (1961) (i.e. at a sorting value of 1,5 in figure 34 and 35) appears, therefore, to be satisfactory.

Both skewness and sorting are dimensionless parameters which describe the sediment population irrespective of the size of the particles. The values shown in figure 35 for the Howison's Poort reservoir form a subset to those shown for Lake Huron. Lake Huron measures approximately 400 by 150 kilometres whereas the Howison's Poort Reservoir measures approximately 1 by 0,1 kilometres. Even though there is such a vast discrepancy of size between the two inland bodies of water, the fact that the dimensionless grain size parameters exhibit graphically very similar patterns illustrates the point that the deposition of sediments in inland bodies of fresh water is similar independent of the size of the water body.

Plots of skewness versus sorting appear, therefore, to provide a useful tool for the identification of the separate groups of sediment within reservoirs. The method is particularly useful when a comparison can be made with plots of sediments from other known environments. The delineation between high energy-and low energy-type deposits made on the basis of the relationship between sorting and skewness values for the sediments is compared to the delineation made on the basis of sorting and mean values in the section that follows.

b) Sorting versus mean grain size

The relationship between sorting and mean grain size parameters (table 4, columns 10 and 11) is plotted in figure 36. For the purposes of running the statistical test program, it is assumed that mean grain size (Y_{mz}) is the independent variable, and sorting (X_{so}) is the dependent variable.75,9% of the variance in sorting values can be accounted for by variance in mean grain size at the 99,99% level of significance (table 6).i.e. the finer the grain size, the poorer the sorting coefficient. From figure 36 it can be noted that there is a considerably higher density of samples with phi values greater than 5 (i.e. finer than 5 phi) and sorting values less than -1,5

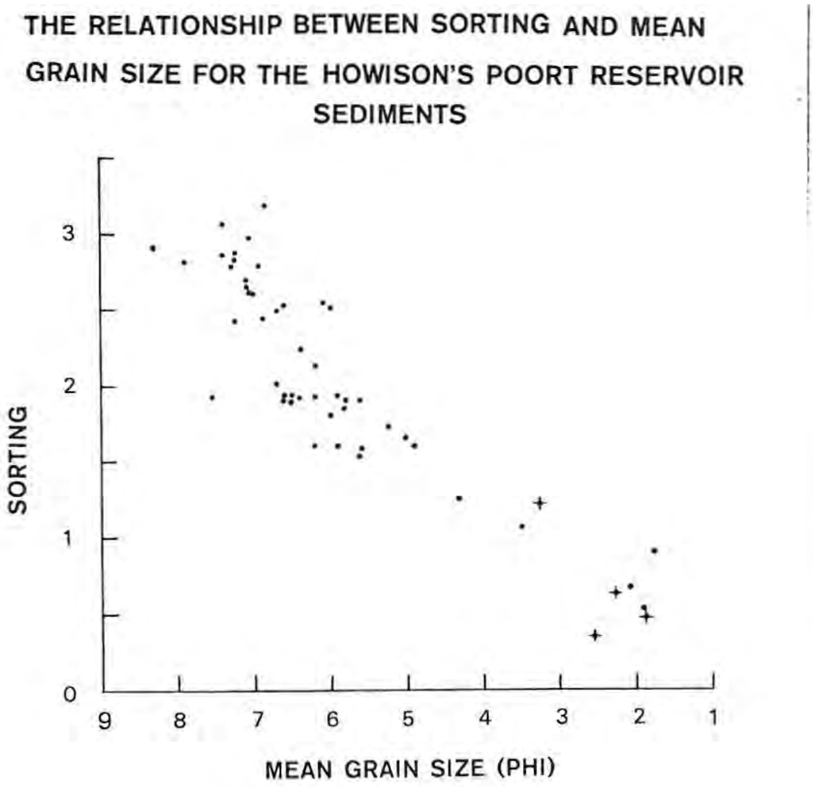


Figure 36.

than those with phi values less than 5 (i.e. coarser than 5 phi) and sorting values greater than -1,5. The latter group of samples coincide with those delineated in figure 34 (i.e. sample numbers 1-9). Using this delineation, two separate groups of sediment can be verbally classified:

1) well to poorly sorted sands,
2) poorly to very poorly sorted silts.

(The sorting values are those suggested by Folk and Ward, 1957; the size ranges are those depicted in the Udden-Wentworth-Lane classification (table 2)).

When these two groups of sediments are considered with respect to the known location of the sediment samples, it is clear that two separate environments of deposition are present. The well to poorly sorted sands along the lower limb of the curve are reflective of high energy conditions with effective hydraulic sorting. The poorly to very poorly sorted silts are reflective of low energy conditions with ineffective hydraulic sorting (chapter 2.3.4.). These two sediment types correspond with those described in chapter 2.1.2., in the discussion of depositional responses to deltaic and density current processes.

From the results described above it appears that a comparison of sorting and mean grain size values of sediment samples is a useful indicator of environmental processes. The hypothesis (2) suggested that two main groups of sediment types would be found within the reservoir, this hypothesis is clearly supported by evidence from sorting/skewness and sorting/mean grain size data. The third method of examining the distribution of textural properties within the reservoir was the use of Passega's pattern C.M. technique (Passega, 1957; 1964).

c) Pattern C.M. Analysis

A C.M. pattern of the Howison's Poort reservoir sediments was drawn by plotting the coarsest one percentile phi values against the median µm values (figure 37). The delineation of depositional environments made by Passega (1957) using this technique (summarized in figure 18) are superimposed on the Howison's Poort C.M. patterns.

Most of the data points generated from study data fall within the group of sediments delineated by Passega (1957) as pelagic or quiet water deposits settling out under conditions described by Stokes' Law (chapter 2.1.1 and 2.2.2.). Samples 1, 2, 4, 5, 6 and 7 fall within one of the relatively high energy environments delineated by Passega (1957). i.e. Beach deposits or fluvial deposits. Samples 3, 8 and 9 fall within areas adjacent to these deposits. There are,

PATTERN CM DIAGRAM OF THE HOWISONS POORT RESERVOIR SEDIMENTS

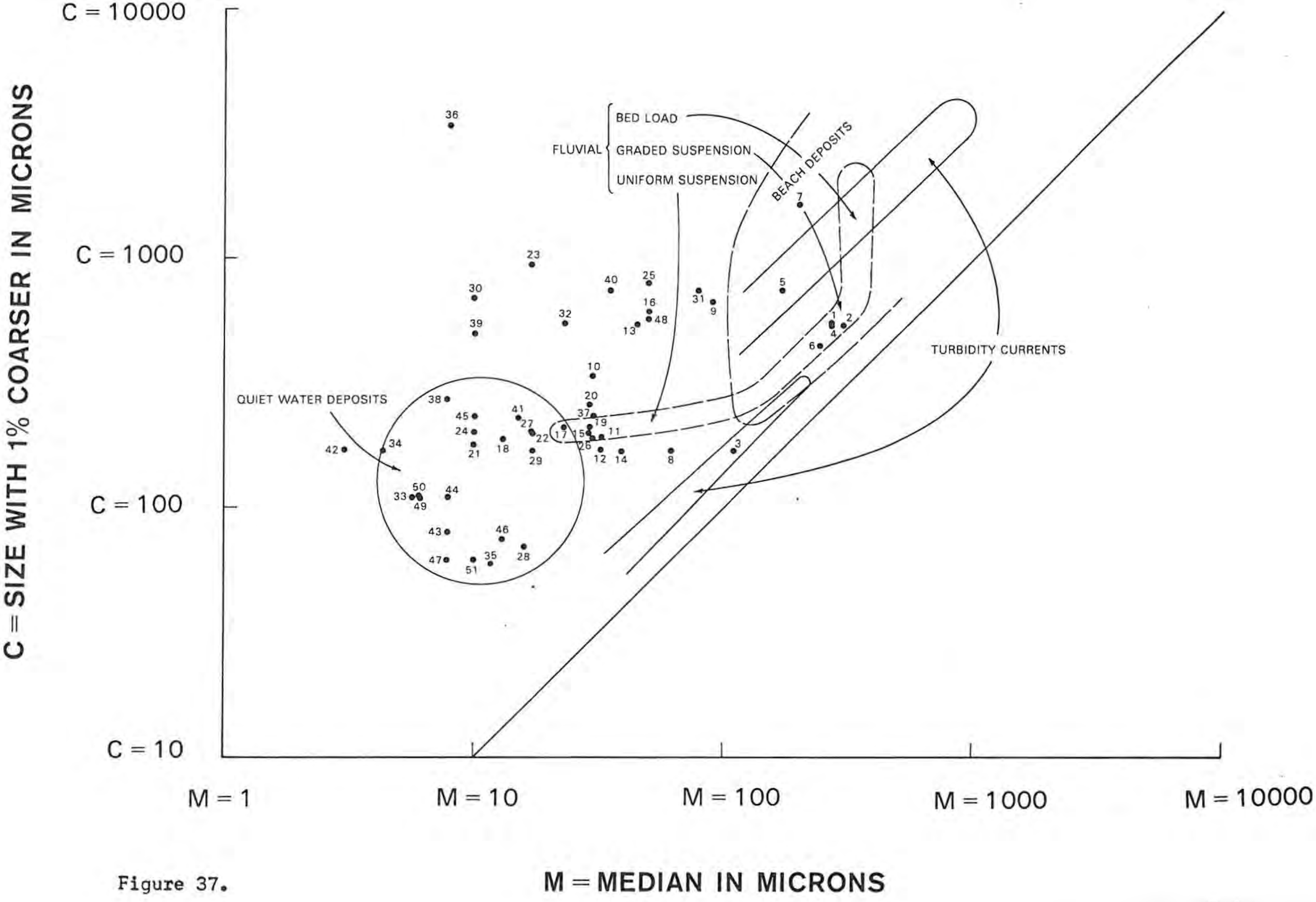


Figure 37.

therefore at least two environments of deposition; a quiet water, relatively low energy environment and a relatively high energy environment.

However, not all sample points fall within or adjacent to the limits suggested by Passega (1957). Samples 10, 11, 12, 14, 15, 17, 19, 20 and 37 all fall within or adjacent to classes delineated as fluvial uniform suspension. These samples all have median and coarsest 1 percentile values intermediate to the quiet water and beach/deltaic deposits. Bearing this in mind and referring to the location of these samples (figure 22) it appears likely that these sediments form a transitional group to the two environments discussed above. A further group of anomalies comprises sediments 13, 16, 23, 31, 30, 32, 36, 39, 40, 46 and 48. All of these sediments have coarsest 1 percentile values greater than the quiet water deposits and median values ranging between those of the two groups delineated above. Referring to figure 22, it is apparent that all of these samples with the exception of sample 16 are located near the reservoir banks. A possible explanation for this group of sediments is that they owe their high C values to the occasional sediment brought into the reservoir during periods of overload flow or during periods of strong winds and bank erosion. A more reliable explanation would probably be forthcoming if it were possible to undertake direct measurement of energy conditions in these areas of the reservoir. However such an investigation would be technically very difficult and was beyond the scope of this study. Passega (1964) notes that CM points falling outside the envelopes suggested probably owe their existence to abnormal events or a combination of conditions. The anomalies identified by pattern C.M. analysis are therefore divided into two groups:

1) those intermediate to sediment identified as deltaic and quiet water deposits and

2) those in marginal areas of the reservoir.

The pattern C.M. analysis of the Howison's Poort sediments substantiates evidence provided in sections (a) and (b) of this chapter that at least two distinctive environments of deposition exist within the reservoir. Section 6.3.2. which follows summarizes the sedimentological implications of the results obtained using the procedures discussed in the section.

6.3.2. Discussion of the results obtained for hypothesis 2.

The three procedures adopted in the previous section to test hypothesis 2 all provided evidence on which the acceptance of the hypothesis is based. It is difficult to assess which of the three procedures provides the most distinct differentiation of depositional response to the sedimentological processes at work in the reservoir. The scattergram showing the relationship between sorting and skewness provides a useful guideline as to where the delineation can be made. This delineation is supported by the results obtained from the examination of the relationship between skewness and sorting values of the sediments. The C.M. pattern provides confirmation of these results and provides insight into the nature and extent of two anomalous groups of sediment. The spatial distribution of sediment response types based on the results obtained from the three procedures are depicted in figure 38. Although it is difficult to assess which procedure provides optimal results, it seems logical to conclude that the conjunctive use of all three procedures is preferable.

The discussion so far has considered only the inorganic component of reservoir sediment. The next section examines in some detail the proportion and distribution of biogenic material within the reservoir. The biogenic components of sediment is a topic largely ignored in the literature although as the following section shows, the relatively

SUBENVIRONMENTS OF DEPOSITION IN THE HOWISON'S POORT RESERVOIR

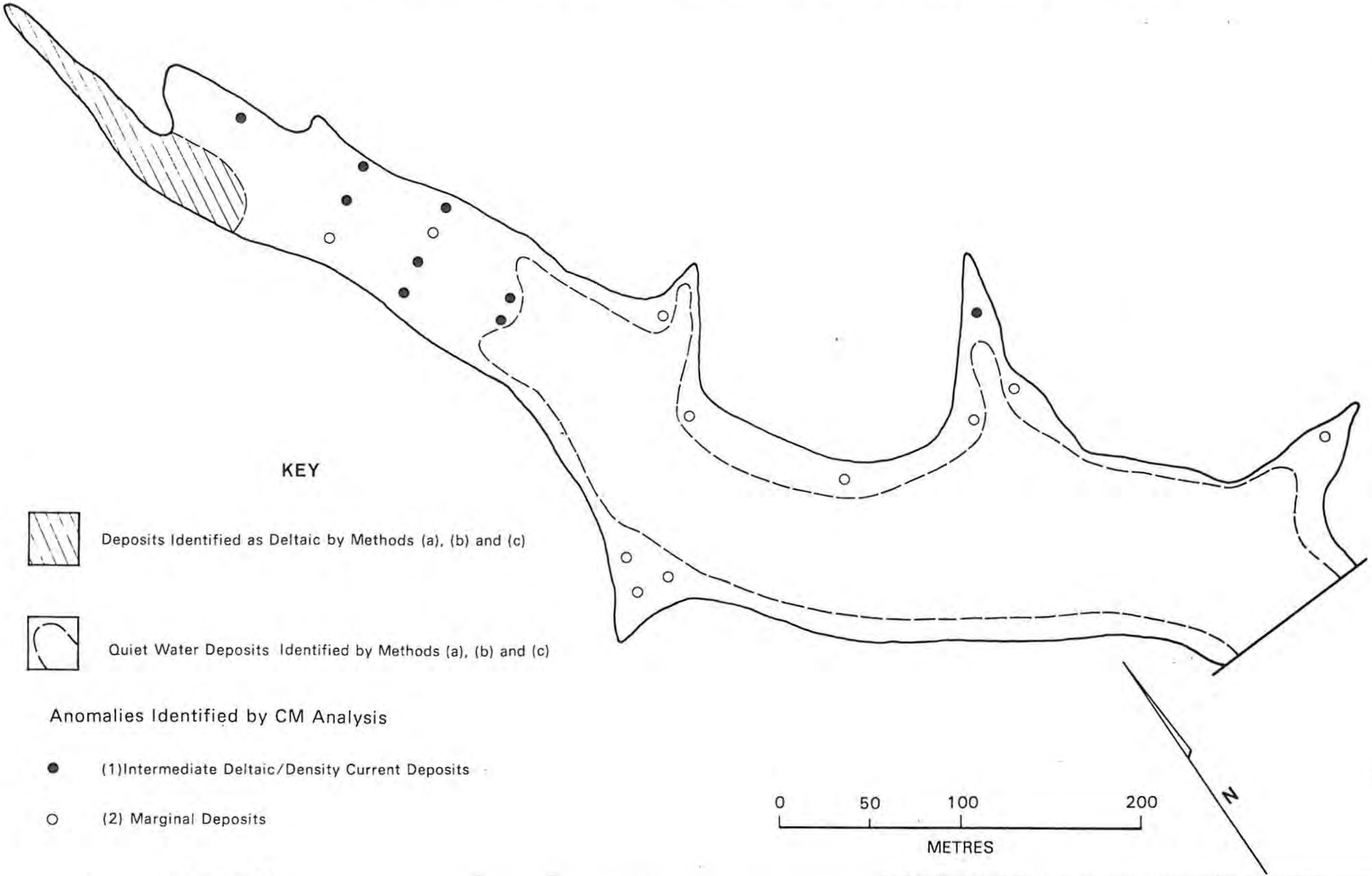


Figure 38.

high proportion of biogenic sediment existing in the Howison's Poort reservoir indicates that biogenic sedimentation is a neglected field of research.

6.4. The Distribution of Biogenic Material.

6.4.1. Hypothesis 3(a)

"The proportion of biogenic material at a given point in the reservoir is directly related to the distance from the nearest reservoir bank".

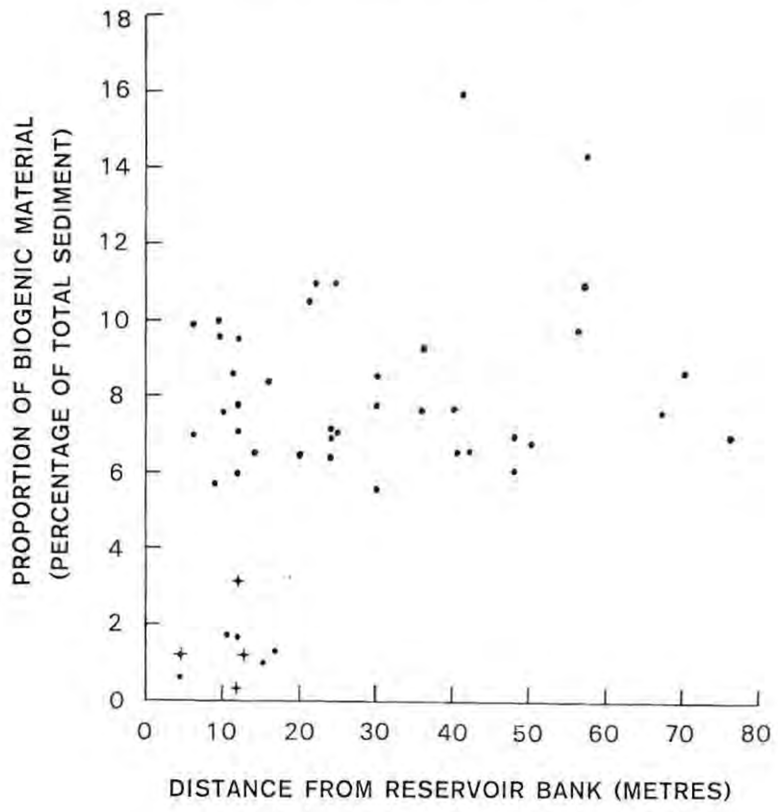
From the known positions of the sediment samples, the distance to the nearest reservoir bank was measured in metres. The biogenic content of the sediment was measured as the weight loss of sediment on ignition at 500°C (see Appendix A for details of the method). Three samples showed exceedingly high biogenic concentration (Numbers 10(45,38%), 29(31,76%) and 45(58,85%)). All three of these samples are located within reed colonies consisting of bull rushes (typha capensis (Rohbr)) and vlei reeds (phragmites australis (Cav.)) (Plate 5). On close inspection of these samples, pieces of reed could easily be distinguished. Based on the classificatory criterion put forward by West (1969) (discussed in chapter 2.2.) these deposits were classed autochthonous. These autochthonous biogenic deposits were excluded from the statistical tests for the six hypotheses that follow, because by definition sediments must be composed of denuded material (Whitten and Brooks, 1975), i.e. material that is transported from its point of origin.

In testing the hypothesis, the distance to the nearest reservoir bank (X_{DB}) (table 4, column 3) was assumed to be the independant variable and the biogenic proportion of total

PLATE 5 : VIEW NORTHWARDS FROM SAMPLE LOCATION 31 SHOWING REED BANKS WHICH SURROUND THE HOWISON'S POORT RESERVOIR.

sediment (Y_B) (table 4, column 8) was assumed to be the dependant variable.

Figure 39 represents the graphical plot of these two variables. The test statistics of these data are presented in table 6 where it is shown that 6,8% of the variance in biogenic material can be accounted for by variations in the distance from the nearest bank at a 90% level of significance. The null hypothesis was therefore accepted and the study hypothesis was rejected at the level of significance set for the study. As was noted when testing hypotheses re the distribution of inorganic sediment, it is likely that the distribution of allochthonous biogenic sediment is influenced to a greater extent by fluvial energy from inflowing streams. The following hypothesis considers the relationship between the proportion of biogenic sediment and the distance to the nearest reservoir tributary.



THE RELATIONSHIP BETWEEN THE DISTANCE
TO THE NEAREST RESERVOIR BANK
AND THE PROPORTION OF BIOGENIC MATERIAL

Figure 39.

6.4.2. Hypothesis 3(b)

"The proportion of biogenic material at a given point in the reservoir is directly related to the distance from the nearest tributary stream".

The distance to the nearest tributary streams were measured from the known positions of the sediment samples within the sediment sub-catchments (delineated in figure 26) to the point of entry of the sub-catchment tributary streams. The proportion of biogenic material was calculated as weight loss on ignition at 550°C (see Appendix A for full details). The distance to the nearest tributary stream (X_{DT})

(table 4, column 5) was assumed to be the independent variable and the proportion of biogenic material (Y_B) (table 4, column 8) was assumed to be the dependent variable. The graphical plot of the relationship between these two variables is given in figure 40.

THE RELATIONSHIP BETWEEN THE DISTANCE TO THE NEAREST TRIBUTARY STREAM WITHIN RESERVOIR SUB-CATCHMENTS AND THE PROPORTION OF BIOGENIC MATERIAL

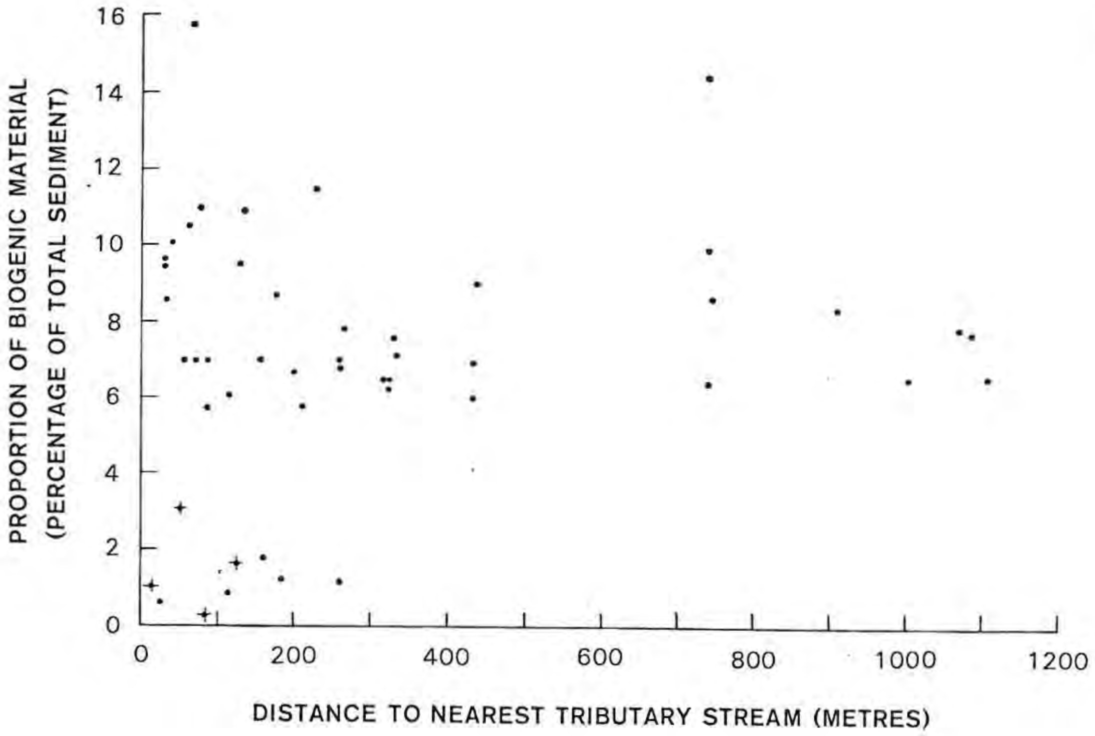


Figure 40.

Table 6 provides the test statistics for the relationship. The level of significance derived from the students t-test is below that set for the study. The null hypothesis is therefore accepted and the study hypothesis is rejected. The result would appear to indicate that tributary streams are unimportant in terms of inorganic sediment input to the reservoir. The volumetric dominance of the main tributary stream in terms of sediment and water has previously been discussed. The hypothesis that follows examines the relationship between the distribution of biogenic sediment and the distance of the sample point from the point of entry of the main stream to the reservoir.

6.4.3. Hypothesis 3(c)

"The proportion of biogenic material at a given point in the reservoir is directly related to the distance from the main stream".

The distance to the point of entry of the main stream was measured from the known position of the sediment samples. The proportion of biogenic material was calculated as the weight loss on ignition (see Appendix A for full details). The distance to the main stream (X_{DM}) (table 4, column 6) was assumed to be the independent variable and the proportion of biogenic material in the sediment (Y_B) was assumed to be the dependent variable (table 4, column 8). The graphical relationship between these two variables is shown in figure 41. The statistical tests applied to this data (table 6) show that 26,1% of the variance in the proportion of biogenic material can be accounted for by variance in distance from the main stream at a 99,9% level of significance. The null hypothesis is therefore rejected and the study hypothesis is accepted.

From the testing of the hypotheses relating the proportion of allochthonous biogenic material to the distances from the nearest reservoir banks, the tributary streams and the main stream to the

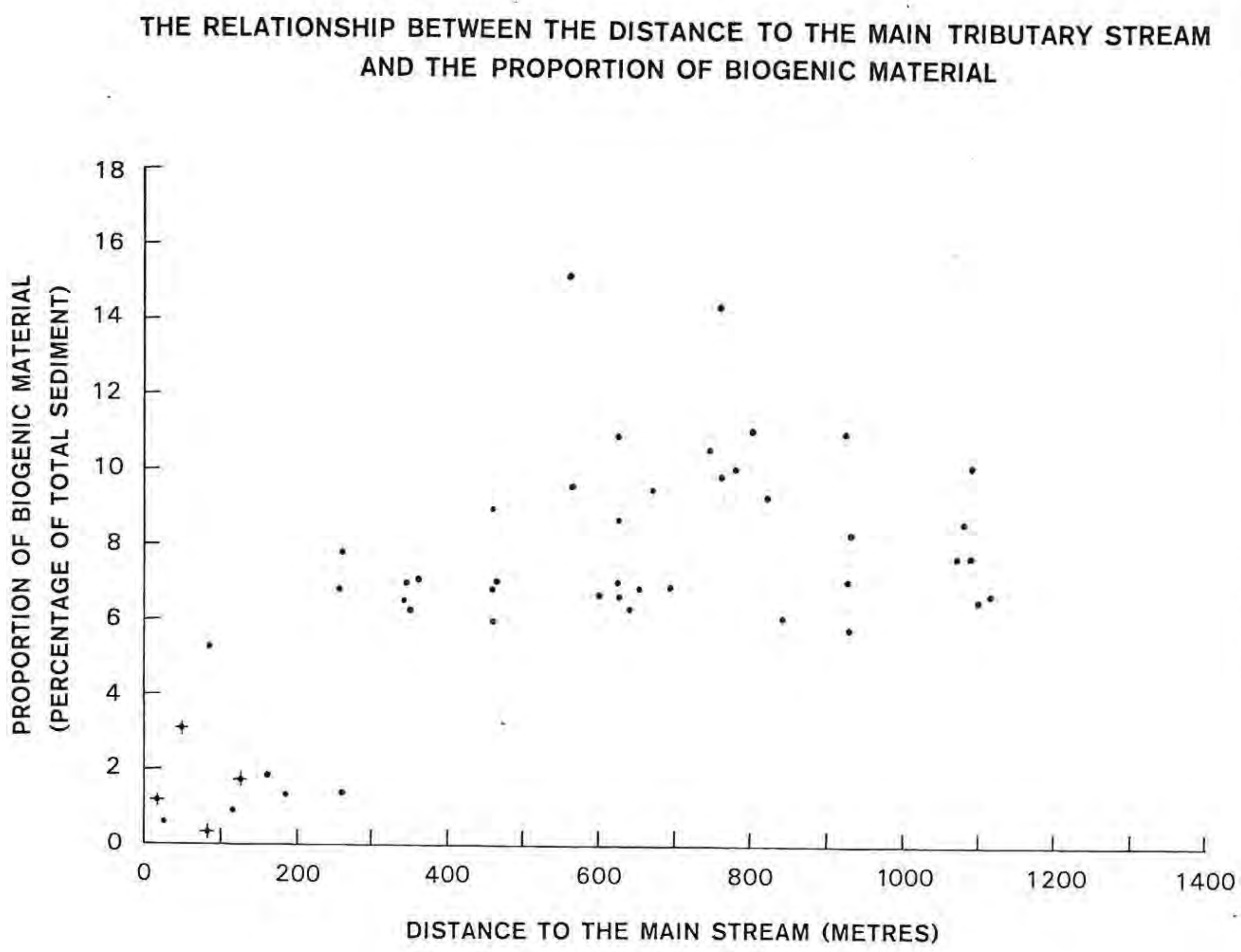


Figure 41.

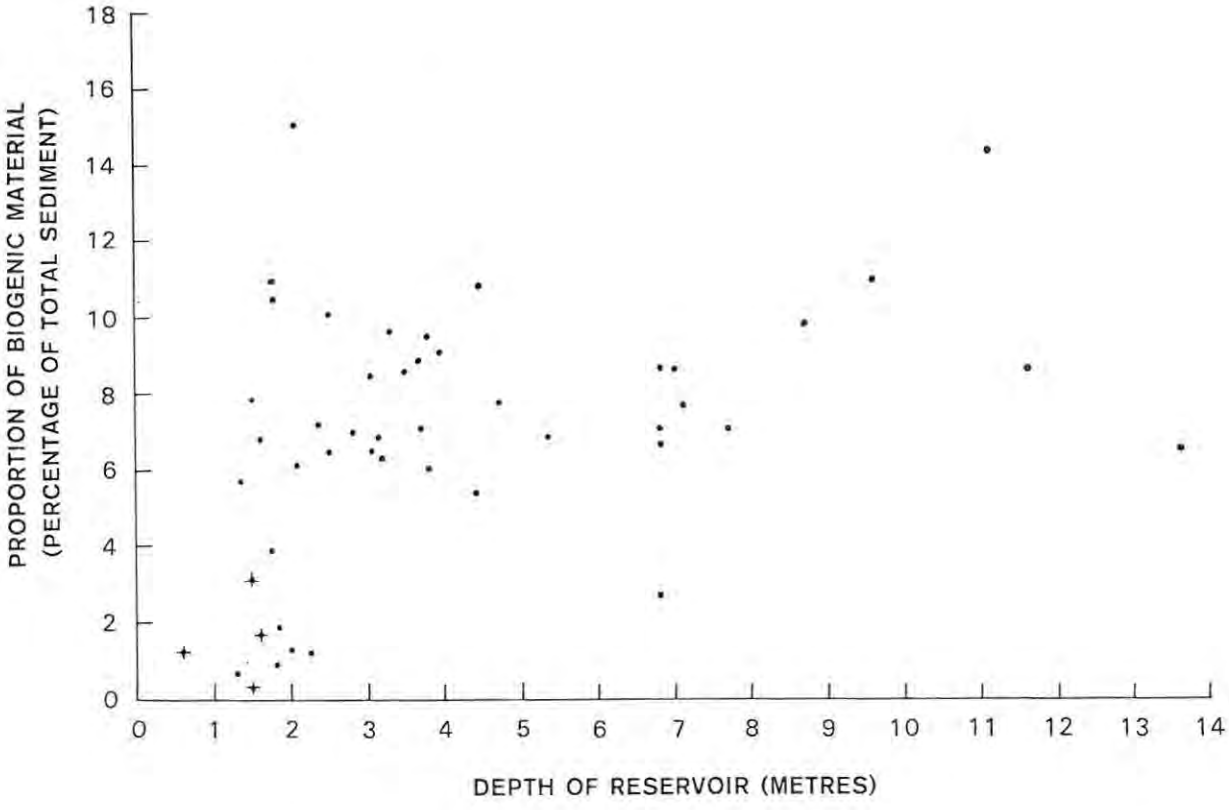
reservoir, it appears that the hydraulic energy introduced by the main stream has the greatest influence on the distribution of the biogenic material.

A further geometrical property of the reservoir is water depth. Hypothesis 3(d) examines the relationship between water depth and the proportion of allochthonous biogenic material.

6.4.4. Hypothesis 3(d)

"The proportion of biogenic material at a given point in the reservoir is directly related to the water depth at that point".

The depth of the water at each sample point was measured at the time of reservoir survey (chapter 5.1.). The proportion of biogenic material was calculated as percentage weight loss on ignition (see Appendix A for full description). The depth of the water (X_{DW}) (table 4, column 7) was assumed to be the independent variable and biogenic content (Y_B) (table 4, column 8) the dependent variable. The graphical relationship between the two variables is shown in figure 42.



THE RELATIONSHIP BETWEEN RESERVOIR DEPTH AND THE PROPORTION OF BIOGENIC MATERIAL

Figure 42.

Consulting table 7, 8,2% of the variance in the proportion of biogenic material can be accounted for by variance in the depth of the water at a 90% level of significance. The null hypothesis is therefore accepted and the study hypothesis is rejected based on the level of significance set for the study. The section that follows summarizes the results obtained in testing hypotheses 3(a), (b), (c) and (d) and the sedimentological implications of these results.

6.4.5. Summary of the results obtained for hypotheses 3(a), (b) (c) and (d).

The possible sources of biogenic material are discussed in chapter 2.2. Hypotheses 3(a), (b), (c) and (d) are based on these possible sources and the mechanisms of water circulation and the distribution of hydraulic energy in reservoirs which is discussed in chapter 2.2. For the purposes of the present study it is assumed that further biogenic matter generated from within the reservoir is equally distributed throughout the reservoir in terms of production.

It appears that the minor tributary streams have little, if any, influence on the distribution of the allochthonous biogenic sediment in the Howison's Poort reservoir. Both the depth of the water and the distance from the nearest reservoir bank show only slight correlation with the proportion of biogenic sediment. For the purpose of the present study, the level of significance of these correlations (90%) is too low to be accepted. The variable most significant to the spatial variation in the proportion of allochthonous biogenic material in reservoir sediment, appears to be the distance between the sample points and the point of entry of the main tributary stream. In terms of the results obtained in the testing of the previous hypotheses, this is not surprising as the main tributary stream appears to be the dominating energy and sediment source controlling sediment accumulation in the Howison's Poort reservoir.

The above results concern only the allochthonous biogenic sediments. Sample numbers 10, 29 and 45 were classified as containing autochthonous biogenic material on the basis of their location, the texture of the biogenic constituents and their exceedingly high biogenic content. The sampling interval adopted did not allow for the inclusion of samples from within the reed banks which vary in width between 1 and 10 metres and occur virtually continuously around the circumference of the reservoir (plate 5). Based on this observation and on the fact that the three samples containing autochthonous biogenic material showed such a high proportion of biogenic matter; it can be concluded that there will be a narrow fringe of sediment containing a high proportion of biogenic matter surrounding the entire reservoir. The extent of this fringe and the concentration of biogenic matter in these sediments is likely to depend upon the depth of the water and upon the biological productivity of the reed banks.

The mean value of the proportion of biogenic material for the 47 samples (i.e. excluding samples 1, 3, 5 and 7) is 7,25% weight loss on ignition at 550°C. The proportion of biogenic to total sediment entering reservoirs via tributary streams was estimated at 0,03 to 0,3% in chapter 2.2. When considering the actual amount present in the Howison's Poort reservoir (7,25%) it is possible that a considerable proportion of biogenic matter is generated from within the reservoir. Assuming the specific gravity to be 1,1 (Hansen, 1959) and that of the inorganic sediment to be 2,65, the percentage by volume of biogenic sediment to total volume sediment can be estimated as 18,77%.

Reservoir capacity displacement estimations based on the amounts of sediment transported by tributary streams overlook the role played by biogenic matter generated from within the reservoirs. It is likely therefore, that such methods underestimate water capacity loss due to sedimentation of reservoirs. The present study is restricted in its scope to the most recent, uppermost layer of sediment in the reservoir. Short term patterns of sedimentation may indicate a higher biogenic content in reservoir sediment than would be the case in the long term. Diagenetic changes and the breakdown of organic material with time would restrict the period for which an individual organic particle would remain in a reservoir effectively displacing water. However, if reducing conditions dominate and the breakdown of particles was inhibited, it is possible that the high biogenic proportion of sediments, shown by the above results, would remain constant over a longer period of time.

The overriding influence of the main tributary stream on the distribution of allochthonous biogenic sediment in the Howison's Poort reservoir reinforces the evidence gained from the results of the previous hypotheses. It appears, therefore that the proportion of biogenic sediment in a sample can be used as a surrogate in the measuring of energy distribution within the reservoir. The following section tests the relationship between the proportion of biogenic matter in reservoir sediment and mean grain size and sorting values which are well documented as being indicators of environmental processes.

6.5. The Relationship between Grain Size Parameters for Inorganic Sediment and the Proportion of Biogenic Material in Reservoir Sediment.

6.5.1. Hypothesis 4(a)

"Covariance exists between the proportion of biogenic material in reservoir sediment and the mean grain size of inorganic sediment".

The biogenic content of the sediment was measured as the weight loss of sediment on ignition at 550°C (Appendix A). Folk and Ward measures were used in describing mean grain size of the inorganic sediment. For the purposes of the running of the statistical tests, mean grain size was assumed to be the independent variable (Y_{MZ}) (table 4, column 10) and the proportion of biogenic sediment was assumed to be the dependent variable (Y_B) (table 4, column 8). The graphical relationship between the two variables is shown in figure 43. 45,3% of the variance in the proportion of allochthonous biogenic sediment is paralleled by a co-variation of the mean grain size of the inorganic sediment at a 99,9% significance level (table 6). The study hypothesis is therefore accepted and the null hypothesis rejected. It is not suggested that a causal relationship exists between mean grain size and the biogenic content but rather that they separately are good indicators of one another and of the prevailing energy conditions of the reservoir which are examined in more detail in the previous hypotheses. A further possible indicator of the distribution of biogenic material, the sorting of the inorganic sediment, is examined in the section that follows.

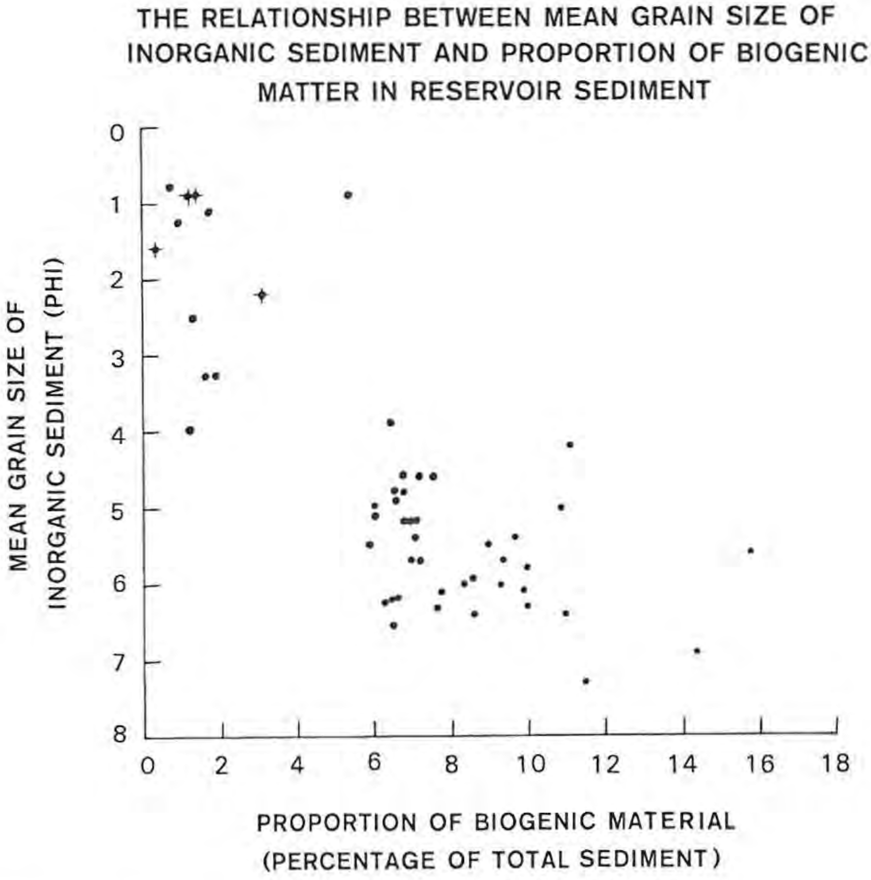


Figure 43.

6.5.2. Hypothesis 4(b)

"Covariance exists between the proportion of biogenic material in reservoir sediment and the sorting values of the inorganic reservoir sediments".

The biogenic content of the reservoir sediment was measured as the weight loss of sediment on ignition at 550°C (Appendix A). Folk and Ward measures were used to determine sorting values. For the purposes of running the statistical test, sorting was assumed to be the independent variable (Xso) (table 4, column 11) and the proportion of biogenic material was assumed to be the dependent variable (Y_B) (table 4, column 8). The graphical relationship between these two variables is shown in figure 45. 38,4% of the variance in the proportion of allochthonous biogenic sediment can be explained by variance in sorting values at the 99,9% level of significance (table 6). The null hypothesis is therefore rejected and the study hypothesis is accepted.

As in hypothesis 4(a), it is not suggested that there is a causal relationship between sorting and the biogenic proportion of reservoir sediments. It is, however, suggested that either measure could be used alone as an indicator of the other, and that both measures are indicators of the energy conditions present in the reservoir environment. The section that follows summarizes the results obtained from the testing of hypotheses 4(a) and 4(b).

6.5.3. Summary of the results obtained for hypotheses 4(a) and (b).

In chapter 2.3. the use of grain size parameters as surrogate measurements of other sedimentary properties was discussed. Hypotheses 4(a) and 4(b) were consequently formulated so that the usefulness of mean grain size and sorting as surrogate measures of the proportion of biogenic material could be assessed. Analysis of the relationship between sorting and mean grain size and the

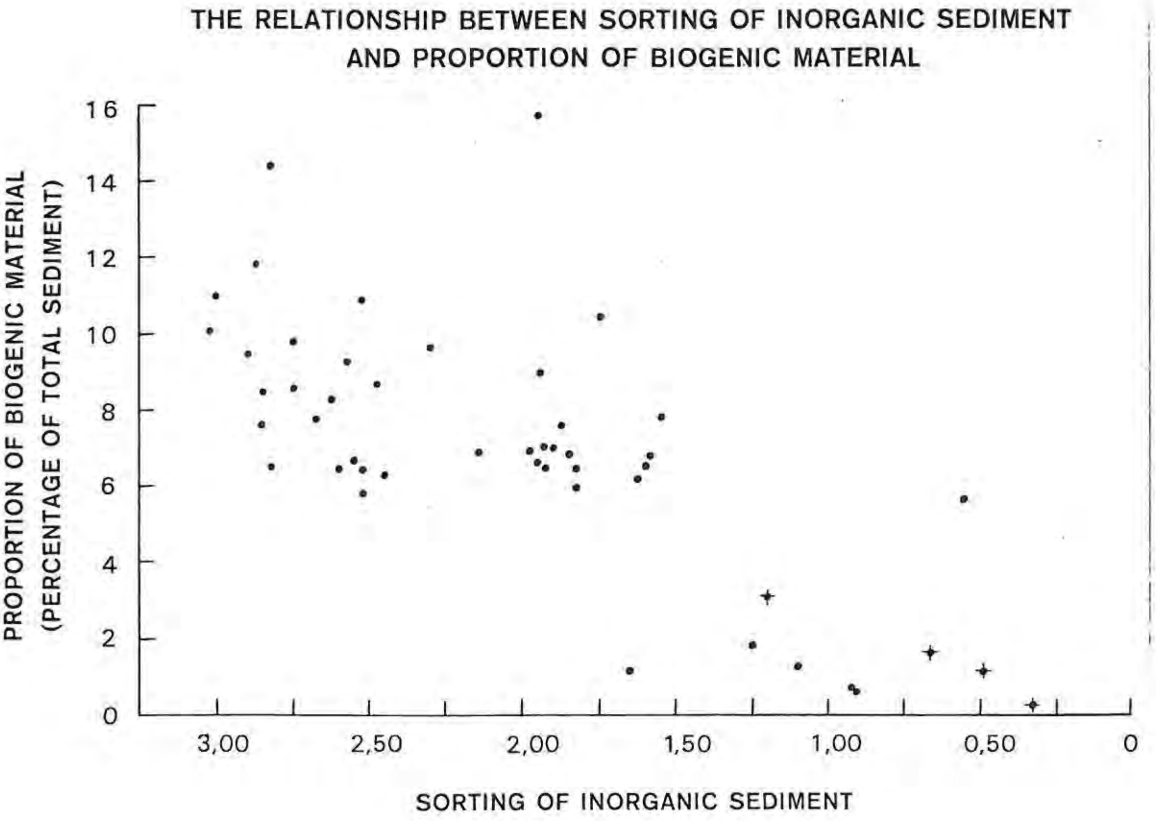


Figure 44.

proportion of allochthonous biogenic sediment reveals that as the sorting values get poorer and the mean grain size values of the inorganic sediment decrease, the proportion of allochthonous biogenic sediment increases. Thus proving the usefulness of mean grain size and sorting measures of inorganic sediment as surrogate measures of the proportion of biogenic material. A further conclusion that can be drawn from these results is that the energy conditions controlling the nature of inorganic response elements also controls the nature of the biogenic response elements; or conversely, that the proportion of allochthonous biogenic material in reservoir sediment can be used as a surrogate measure of environmental conditions.

CHAPTER 7

CONCLUSION

The empirical study of the sedimentary characteristics of the Howison's Poort reservoir has provided a detailed record of spatial variations of sedimentary properties, thus fulfilling the first aim of the thesis. The consideration of these spatial variations against the background of existing theory was the second main aim of the study. The final study aim, an assessment of the applicability of grain size parameters in the identification of sedimentary patterns was discussed in detail in chapter 6.3.

In chapter 2.4 the use and application of a process and response model as a basis to the present study was discussed. This final section (chapter 7) summarizes the results of the study in terms of a response model of a reservoir under constant process conditions. The model is put forward as a proposed basis for a universal model of the patterns of sediment distribution in reservoirs. The model is based on the findings of the present study and the basic theories of reservoir hydraulics outlined in chapter 2.

The model is schematically presented in figure 45. The numbers listed along each cross-section represent the positions of hypothetical sample points. The sedimentological attributes of these samples are explained in table 7. The two basic characteristics of the reservoir sediments examined in this study are selected textural features of the inorganic sediment and the proportion of biogenic matter in the total sediment. Two major classes of inorganic sediment were found to exist in the reservoir, namely those sediments classified as deltaic-type deposits (Class I) and those sediments classified as density current-type deposits (Class III). The former was found to consist of well sorted, relatively coarse grained deposits, whilst the latter consist primarily of poorly sorted, relatively fine grained deposits. A further group of sediments which has limited extent in the Howison's Poort reservoir are marginal-type deposits (Class II). Marginal-type deposits include those sediments which probably owe their characteristics to wind generated

SCHEMATIC DIAGRAM OF THE SPATIAL VARIATION OF
SURFICIAL RESERVOIR SEDIMENT CHARACTERISTICS

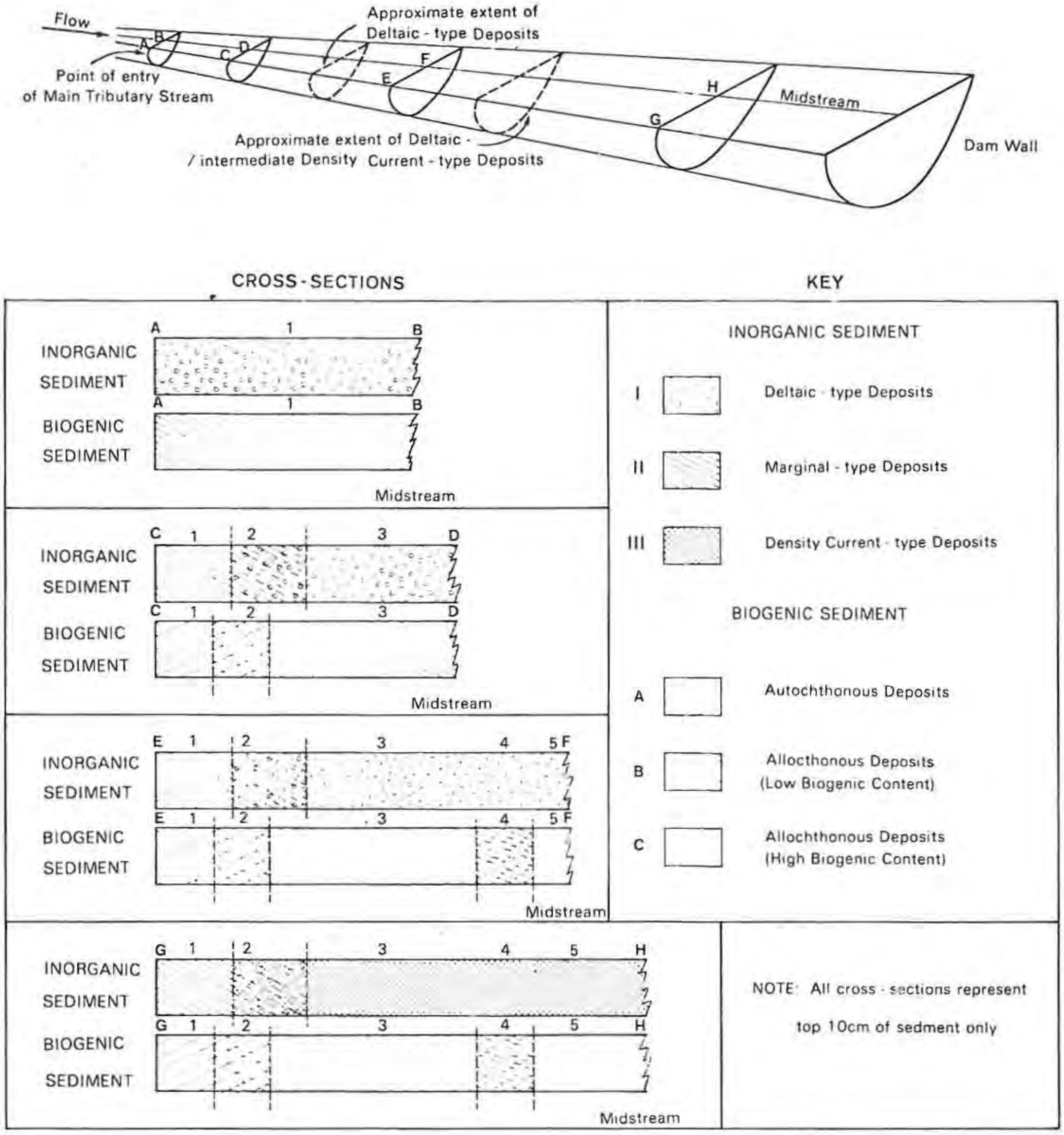


Figure 45.

turbulence in the epilimnion or to abnormal conditions of overland flow. The former process prevents the settling out of particles within the Stokes' range of settling velocities and the latter process adds poorly sorted sediment to the existing deposits during periods of intense rainfall. Class II deposits are poorly sorted and relatively coarse grained in areas of no stream flow (Twenhofel, 1950, see chapter 2.1.2.) but will supposedly merge into well sorted coarser sediments in areas where the energy generated by streamflow

TABLE 7 : EXPLANATION OF THE POINTS NUMBERED IN FIGURE 45

Cross-Section	Point Number	Set Notation	Verbal Description Inorganic	Verbal Description Biogenic
A B	1	I∩B	Well sorted, coarse grained sediments	Low allochthonous biogenic content
C D	1	II∩B	Poorly sorted, coarse grained sediments	High autochthonous biogenic content
	2	(I∩II)∩(A∩B)	Fairly well to well sorted, coarse grained sediments	Low autochthonous and low allochthonous biogenic content
	3	I∩B	Well sorted, coarse grained sediments	Low allochthonous biogenic content
E F	1	II∩A	Fairly well sorted, medium to fine grained sediments	High autochthonous biogenic content
	2	((I∩III)∩II)∩(A∩B)	Fairly well to well sorted, medium to fine grained sediments	Low allochthonous and low autochthonous biogenic content
	3	(I∩III)∩B	Poorly sorted, medium to fine grained sediments	Low allochthonous biogenic content
	4	(I∩III)∩(B∩C)	Poorly sorted, medium to fine grained sediments	Medium allochthonous biogenic content
	5	(I∩III)∩C	Poorly sorted, medium to fine grained sediments	High allochthonous biogenic content
G H	1	I∩A	Poorly to very poorly sorted medium to fine grained sediments	High autochthonous biogenic content
	2	(II∩III)∩(A∩B)	Poorly to very poorly sorted fine grained sediments	Low autochthonous and low allochthonous biogenic content
	3	III∩B	Very poorly sorted fine grained sediments	Low allochthonous biogenic content
	4	III∩(B∩C)	Very poorly sorted fine grained sediments	Medium proportion allochthonous biogenic content
	5	III∩C	Very poorly sorted fine grained sediments	High allochthonous biogenic content

NOTE : ∩ = intersection between two classes dominates. The three major classes of inorganic sediment types described above are not separated by distinct boundaries; between each an inter= mediate or mixing zone is identified.

The biogenic proportion of reservoir sediment is divided into three classes in the reservoir response model. In chapter 6 it was noted that there is a fringe of reed banks surrounding the reservoir. The biogenic sediment within this zone is deposited at its point of origin and can therefore be classed as being autochthonous biogenic sediment (class A) as it has not undergone transportation. Autochthonous biogenic deposits include a high proportion of biogenic matter, as high as 58,85% for the Howison's Poort reservoir sediments. Allochthonous biogenic deposits are represented in the model by two classes, class B and C, these two classes contain biogenic matter deposited distal to its point of origin. Allochthonous biogenic deposits are divided into two classes for the sake of convenience and to show more clearly the existing trends. Class B comprises allochthonous biogenic deposits exhibiting a relatively low proportion of biogenic matter and class C comprises those with a relatively high proportion of biogenic matter. In the Howison's Poort reservoir it was found that there is a direct relationship between the proportion of allochthonous biogenic matter in the sediment samples and the distance from the point of entry of the main stream. Other research workers (e.g. Thomas, Kemp and Lewis, 1972; Zapol'sky and Yes'kov, 1976) have also noted a relationship between the depth and the proportion of allochthonous biogenic matter in total sediment. Intermediate zones of biogenic sediment types exist in areas between these three classes.

No absolute values are given for grain sizes, sorting values or biogenic proportions in the model as these will vary with varying magnitude of the process elements. The boundaries allocated in figure 45 must also be considered as being variable depending upon the environmental conditions of a given impoundment. For example, the extent and mean grain size of the deltaic-type deposits will depend on stream discharge, the mean grain size of the transported sediment, the slope of the reservoir thalweg and the variability of reservoir water level. The extent and proportion of the autochthonous biogenic sediment will vary with the depth of the marginal areas and the biological productivity of these areas.

The true test of the model is if it is found to be applicable to reservoirs of varying shapes, depths and sizes in areas of different topography, land-use and climate. Further studies on the variations of sediment characteristics with depth of deposits and of particles in suspension in reservoirs will enable the development of a three-dimensional response model of reservoir sediment characteristics. The inferred relationships between the process and response elements of the model can only be confirmed by the technically more difficult direct measurement of reservoir hydraulics.

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APPENDIX A

'METHOD OF ANALYSIS USED FOR THE DETERMINATION OF BIOGENIC MATTER BY IGNITION LOSS. (Grant-Gross, M.G. 1971, in Carver (ed), 1971, pp. 586-587)

A.1. Apparatus

Furnace capable of operating continuously at 600°C, porcelain crucibles, dessicator.

A.2. Reagents

None.

A.3. Procedure

a) Transfer a weighted sample of ground sediment that has been dried at 110°C for 3 hours or more and place in crucible.

b) Place crucible in electric muffle furnace and heat at 550°C for 1 to 2 hours.

c) Cool partially in air and then transfer to dessicator for cooling to room temperature.

d) Remove from dessicator and reweigh; calculate weight loss as percentage of initial weight of sample.

e) Report as ignition loss (550°C).

APPENDIX B

METHOD OF ANALYSIS USED FOR THE DETERMINATION OF MEAN GRAIN SIZE.

(Based on the methods set out by the British Standards Institution, 1975).

B.1. Apparatus

British standards hydrometer; two 1000ml graduated glass measuring cylinders; British standard test sieves 850μm, 500μm, 125μm, 63μm and a receiver; a mechanical shaker; a balance readable and accurate to 0,01g; an oven, capable of operating continuously at 105°C to 110°C; a stop clock; a wash bottle containing distilled water; a 100 ml measuring cylinder; a glass rod; a pipette; a rubber bung and a thermometer.

B.2. Reagents.

A 20 volume hydrogen peroxide solution; a sodium hexametaphosphate solution (33g sodium hexametaphosphate, 7g sodium carbonate dissolved in distilled water to make a 1 litre solution).

B.3. Pretreatment of the Soil.

B.3.1. Extract approximately 100g from the parent sample and place in beaker of known weight.

B.3.2. Add 150 ml of a 20 volume solution of hydrogen peroxide (using a 100 ml measuring cylinder) and stir gently for a few minutes (break gas bubbles with a jet of distilled water from a gas bottle).

B.3.3. Leave mixture to stand overnight.

B.3.4. Warm liquid gently, stirring with a glass rod. Once vigorous frothing subsides, dry soil in an oven at 110°C.

B.3.5. After a drying period of at least 10 hours, allow the soil sample and beaker to cool and measure the weight (wb) of the pretreated soil accurately to 0,01g.

B.4. Soil Dispersion

B.4.1. Add 100 ml of sodium hexametaphosphate solution to the soil in the beaker (using a pipette). Stir the solution (using a glass rod) and warm gently for 10 minutes. Allow the solution to cool.

B.4.2. After cooling, agitate the liquid once again and allow the suspension to settle for 2 minutes. Decant the liquid suspension onto a 63 micron sieve, ensuring no loss from spillage and the retention of aggregates and relatively coarse particles in the beaker.

B.4.3. Add distilled water to the beaker and repeat B.4.2, until the liquid is clear.

B.4.4. Transfer the residue in the beaker to the 63 micron sieve into an evapourating dish. Dry in an oven at 110°C in preparation for dry sieving.

B.4.5. Transfer the material finer than 63 microns from the retainer into a 1000 ml measuring cylinder using a porcelain funnel and a jet of distilled water. Add distilled water to the suspension in the cylinder making it up to a 1000 ml volume in preparation for the hydrometer analysis.

B.5. Dry Sieving

B.5.1. Weigh the oven dried sample (B.4.4.) to the nearest 0,1% of its mass.

B.5.2. Select a set of sieves with the largest sieve appropriate to the maximum grain size present and finer sieves ranging in size down to 63 microns. (The sieves used ranged between 850 and 63 microns).

B.5.3. Place the dried, weighed samples on the uppermost sieve. Place a lid on the top sieve and a catch pan below the finest sieve.

B.5.4. Clamp the nest of sieves in the mechanical shaker and allow to vibrate for 12 minutes.

B.5.5. Record the weight of sediment retained on each sieve and report on data sheet as shown in table B.1.

B.6. Hydrometer Analysis of Fines.

Sedimentation

B.6.1. Calibrate the hydrometer as set out by the British Standards Institution (see note).

B.6.2. Insert a rubber bung in the mouth of the measuring cylinder (B.4.5.) and shake vigorously until a uniform suspension is formed.

TABLE B.1.

HOWISON'S POORT

PARTICLE SIZE ANALYSIS - DRY SIEVING, DATA SHEET

Sample number 9 Project number HOWP

Location HOWISON'S POORT

Description RESERVOIR SEDIMENT

Date of analysis 13th June, 1978 Operator A. WEAVER

Weight of container 162,13g

Weight of sample + container 217,01g

Weight of sample 54,88g

diameter µm	diameter ø	weight retained	% retained	% passing
850	0,25	0,00	0,00	100
500	1,00	0,18	0,33	99,67
212	2,20	0,99	1,80	97,87
125	3,00	17,41	31,72	66,15
63	4,00	14,74	26,86	39,29
00		0,91	1,66	35,97

B.6.3. Allow cylinder to stand and start stop watch immediately. Immerse hydrometer and allow to float freely.

B.6.4. Take hydrometer readings after 1 minute, 2 minutes and 4 minutes. Remove hydrometer slowly, rinse in distilled water and allow it to float in a cylinder of distilled water at the same temperature as the soil suspension.

B.6.5. Carefully insert the hydrometer after 8, 15, and 30 minutes, 1,2, and 4 hours of lapsed time. After each reading, remove the hydrometer, rinse it and place it in the cylinder of distilled water.

B.6.6. Record the temperature of the suspension (to the nearest 0,5C) during the first 15 minutes and, subsequently, after each density reading.

B.6.7. Record further readings if necessary.

B.7. Calculations

B.7.1. Fill in observed data and computed quantities on a table as shown in table (B.2.) where:

Rh^1 = the hydrometer reading at the upper rim of the miniscus;
Cm = the miniscus correction;
Mt = the temperature correction (figure B.1.)
X = the dispersing agent correction.

B.7.2. The equivalent particle diameter, D, is determined by means of the nomographic chart for the application of Stokes' Law (figure B.2). A value of the constant B is obtained by placing a straight edge across the hydrometer reading, Rh, and time, t, scales at the appropriate values.

B.7.3. A value for the equivalent particle diameter, D, is obtained by placing a straight edge aross the velocity and B scales at points corresponding to the values of B and V found in B.7.2 and B.7.1. The values of the equivalent particle diameters thus obtained are entered in column 7 of table B.2.

TABLE B.2.: HOWISON'S POORT

PARTICLE SIZE ANALYSIS - HYDROMETER

SAMPLE NO. ....9..........

(1) Date	(2) Time	(3) Temperature	(4) Elapsed time	(5) R_h^1	(6) $R_h = R_h^1 + C_m$	(7) D	(8) $R_h + M_t - x$	(9) K%
13.6.78	10.06	12°C	1 min	5,30	6,2	67	4,0	11,84
13.6.78	10.07	12°C	2 min	5,20	6,1	47	3,9	11,54
13.6.78	10.09	12°C	4 min	5,05	5,95	33	3,8	11,25
13.6.78	10.10	12°C	8 min	4,40	5,3	24	3,1	9,18
13.6.78	10.20	12°C	15 min	3,50	4,4	17	2,2	6,51
13.6.78	10.35	12°C	30 min	3,00	3,9	12	1,7	5,03
13.6.78	11.05	12°C	1 hr	3,00	3,9	8	1,7	5,03
13.6.78	12.05	13°C	2 hr	2,50	3,4	6	1,2	3,55
13.6.78	14.05	13°C	4 hr	1,50	2,4	4,5	0,2	0,59

TEMPERATURE CORRECTION CHART FOR HYDROMETERS CALIBRATED IN DENSITY AT 20°C

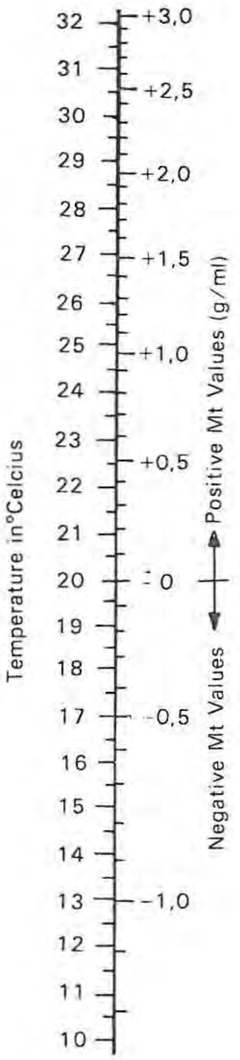


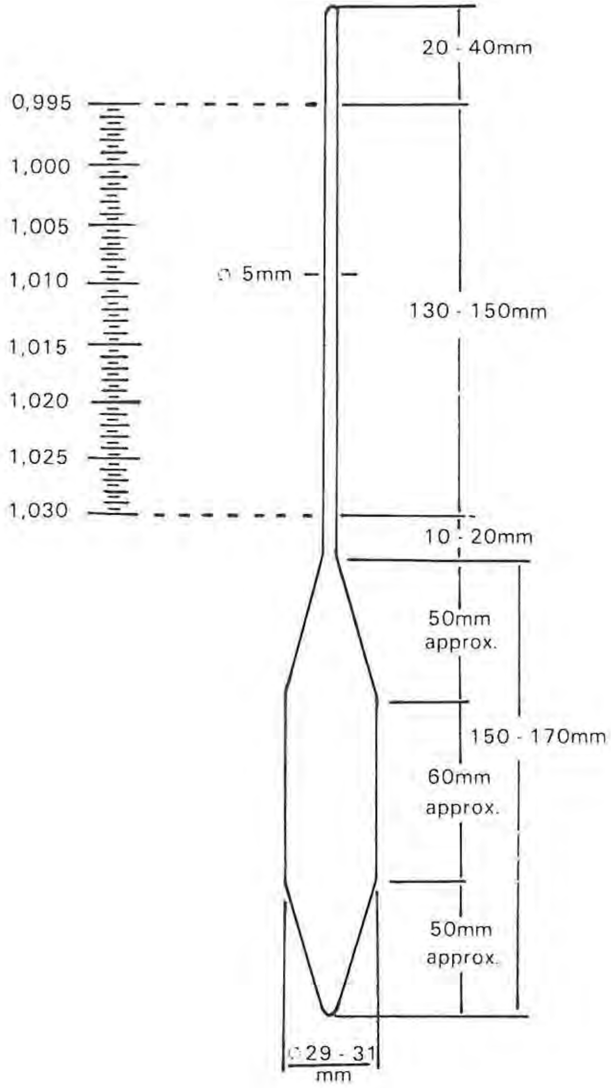
Figure B.1.

B.7.4. The temperature correction, Mt, is obtained from the temperature correction chart (figure B.1.) and added to the quantity (Rh-x) and recorded in column 8 of table B.2.

B.7.5. The percentage by mass, K, of the particle smaller than the corresponding equivalent particle diameters is calculated using the equation:

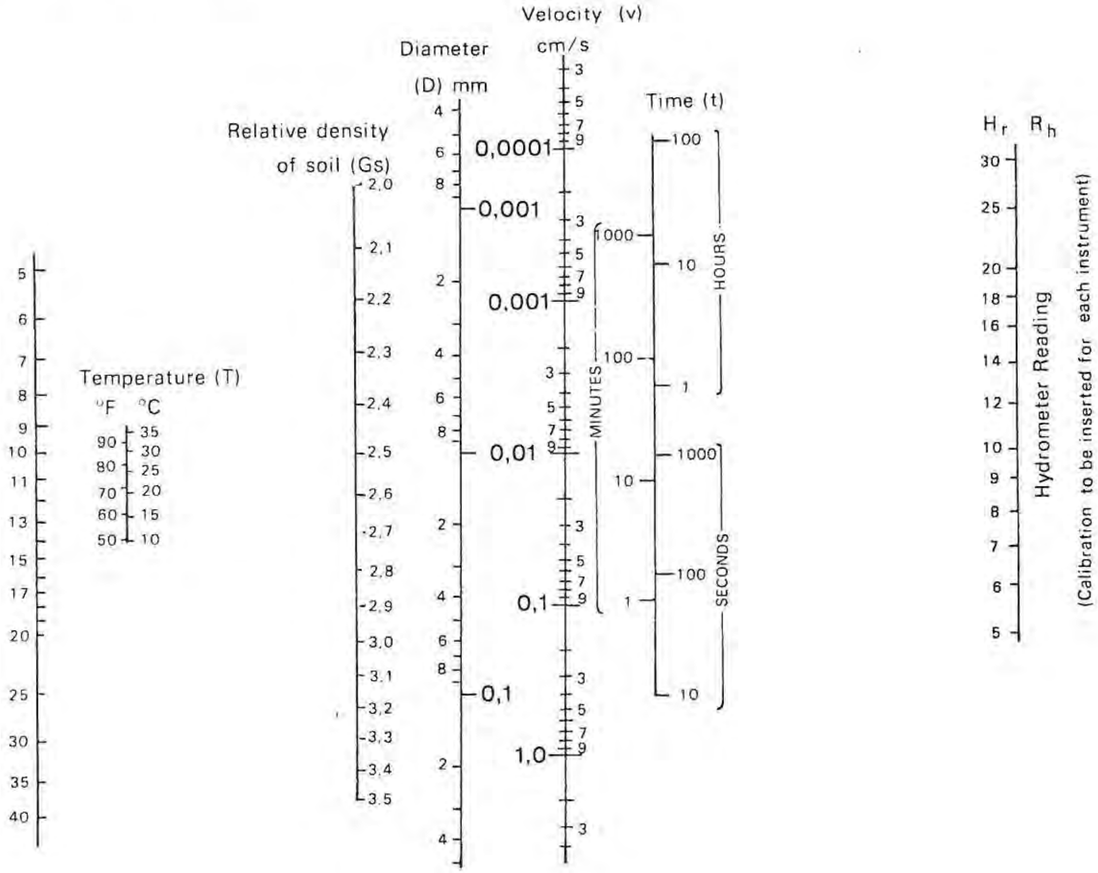
$$K = \frac{100\ Gs}{m(Gs-1)}\ (Rh + Mt-x)$$

NOMOGRAPHIC CHART FOR THE APPLICATION OF STOKES' LAW.



NOTE Calibrations in g/ml to read 1,000 at 20 C

HYDROMETER FOR THE DETERMINATION OF PARTICLE SIZE IN SOIL



NOTE: Calibrations are in g/ml at 20 C All dimensions are in millimetres.

NOMOGRAPHIC CHART FOR USE WITH HYDROMETERS

Figure B.2.

where m = the total dry mass of soil after pretreatment

Gs = the relative density of soil particles (assumed to be 2.65)

B.7.6. Values of K are calculated for every value of D obtained and are expressed as percentages finer than the corresponding values of D. (table B.2, column 9).

B.8. Note

Calibration of the hydrometer.

B.8.1. Volume

a) The volume of the hydrometer bulb, Vh, is determined by the volume of water displaced.

b) Approximately 800 ml of water is poured into a 1000 ml measuring cylinder. The reading of the water level is observed and recorded.

c) The hydrometer is then immersed in the water and the level is again observed and recorded. The difference between the two readings is recorded as the volume of the hydrometer bulb in millimetres.

B.8.2. Calibration of hydrometer. (refer to figure B.2).

a) The cross-sectional area of the 1000 ml measuring cylinder is calculated by measuring the distance between two gradations on the measuring cylinder and dividing this distance into the volume included between these two gradations.

b) The distances from the lowest calibration mark on the stem of the hydrometer to each of the other major calibration marks, Rh, is measured and recorded.

c) The distance from the neck of the bulb to the nearest calibration mark is measured and recorded.

d) The distance, H, corresponding to a reading, Rh, is equal to the sum of the distances measured in (b) and (c).

e) The distance, h, from the neck to the bottom of the bulb is measured and recorded as the height of the bulb.

f) The effective depth, Hr, corresponding to each of the major calibration marks, Ph, is calculated from the formula:

$$Hr = H_1 + {}^1/2\ (h - \frac{Vh}{A}).$$

where H_1 = the length from neck of bulb to gradation Rh (mm);

h = twice the length from neck of bulb to its centre of volume (mm);

Vh = the volume of hydrometer bulb (ml);

A = the area of measuring cylinder (mm^2)

g) The relationship between Hr and Rh is plotted as a smooth curve (figure B.3); using the smooth curve so obtained, a scale of Rh values is constructed to the right of the Hr scale for the application of Stokes' Law. (figure B.2.).

B.8.3. Meniscus correction

a) The hydrometer is immersed in a 1000 ml measuring cylinder containing 700 ml water.

b) The eye is positioned slightly below the plane of the surface of the liquid and then raised slowly until the surface seen as an ellipse becomes a straight line. The point where the plane intersects the hydrometer is determined.

c) The eye is positioned slightly above the plane of the surface of the liquid, the point where the upper limit of the meniscus intersects the hydrometer is determined.

d) The difference between the two readings taken in (b) and (c) above is recorded as the meniscus correction, Cm.

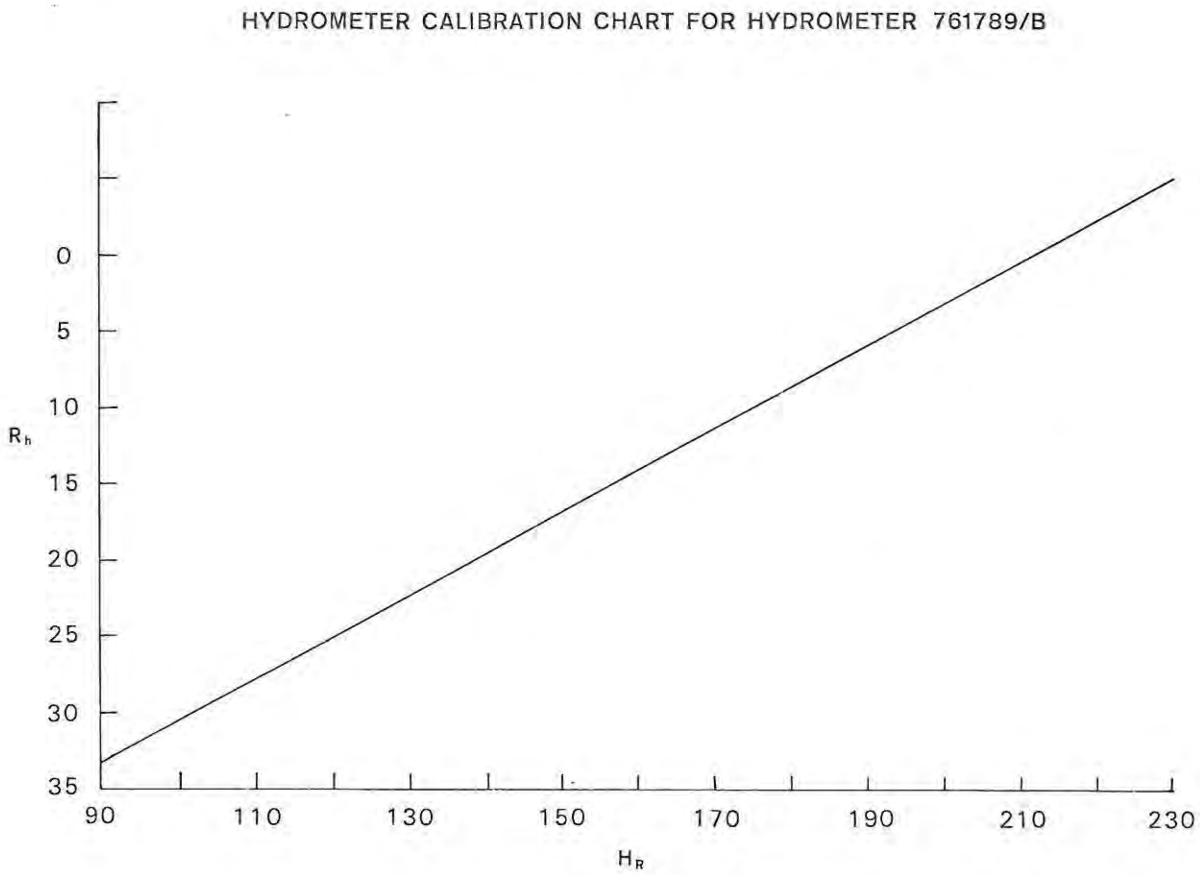

HYDROMETER CALIBRATION CHART FOR HYDROMETER 761789/B
0
5
10
15
20
25
30
35
R_h
90
110
130
150
170
190
210
230
H_R

Figure B.3.

APPENDIX C

CALCULATION OF GRAIN SIZE PARAMETERS

The grain size parameters calculated for the present study were mean, sorting, skewness, kurtosis, median and the coarsest percentile. These values were calculated using a FORTRAN computer program compiled by D. Gilson (1977) (the program is listed in appendix C.2.).

C.1. Description of the program.

The program does the following:

1. Read the value of the weights measured per sieve phi size;
2. Calculates the total weight of the samples;
3. Calculates the percentage of total sample retained;
4. Calculates the percentage passing per phi value;
5. Fits a cubic spline polynomial to the percent (Y) versus phi value (X);
6. Calculates the mean, sorting, skewness, kurtosis, median and coarsest one percentile of each sample;

When compared to manually calculated values for the same parameters, the program used shows an error of less than 0,03 ϕ; an error small enough to be of no significance. Where sediments were analysed using both sieving and hydrometer methods, the data input was in the form of percent retained per sieve phi size (C.3.). Where only sieves were used the input consisted of weights retained per sieve phi size (C.4.).

C.2. Program Used for the Calculation of Grain Size Parameters.

```
-----------------------------------------------------------------------------
       DATE 19/12/78    TIME 14/30/35                          LISTING FOR:- GGA

FILE:   GGAWMAXIMOP     SUBFILE P123 IN CARD MODE

      SHORTLIST
      LIBRARY (SUBGROUPPLOT)
      LIBRARY (AMPTROUTINES)
      PROGRAM (FORT)
      COMPACT
      COMPRESS INTEGER AND LOGICAL
      INPUT 1,5 = CR0
      INPUT 4 = CR1
      OUTPUT 2,6 = LP0
      OUTPUT 7 = LP1
      TRACE 2
      END
      MASTER FITCURV
C THIS PROGRAM USES CUBIC SPLINE POLYNOMIAL INTERPOLATION TO FIT
C  SMOOTH CURVES TO DATA POINTS

      DIMENSION PHI(30),WT(30),XI(200),YI(200),V(200),
     *A(200),B(200),C(200),D(200),RET(30),PAS(30),LOCA(30),
     *DATE(20),SAMPLE(10),PROJ(30),DESCN(30),OPER(20)
      XS=10.0
      YS=10.0

C READ NUMBER OF SAMPLE POINTS, NPOINTS.

5     READ (5,51) NPOINTS
51    FORMAT (I2)

C IF NPOINTS = 0, THEN PROGRAM WILL TERMINATE.

      IF (NPOINTS.EQ.0) GO TO 40

C  READ LOCATION.

      READ (5,1) LOCA
1     FORMAT (30A1)

C READ DATE.

      READ (5,2) DATE
2     FORMAT (20A1)

C READ SAMPLE NUMBER.

      READ (5,3) SAMPLE
3     FORMAT (10A1)

C READ PROJECT DESCRIPTION.

      READ (5,4) PROJ
4     FORMAT (30A1)

C READ DESCRIPTION OF DATA.

      READ (5,98) DESCN
98    FORMAT (30A1)
C READ OPERATORS NAME.
```

```
      READ (5,6) OPER
6     FORMAT (20A1)

      DO 10 K=1,NPOINTS

C READ IN DATA POINTS IN ORDER: PHI VALUE, WEIGHT RETAINED; STARTING
C AT ZERO WEIGHT RETAINED.

      READ (5,52) PHI(K),WT(K)
52    FORMAT (2F8.2)
10    CONTINUE

C CALCULATE TOTAL WEIGHT OF SAMPLE.

      SUM = 0.0
      DO 110 MM = 1,NPOINTS
110   SUM = SUM + WT(MM)

C CALCULATE % RETAINED.

      TOT = 0.0
      DO 112 MN = 1,NPOINTS
      RET(MN) = (WT(MN)/SUM)*100.0
      TOT = TOT + RET(MN)

C CALCULATE % PASSING.

112   PAS(MN) = 100.0 - TOT

C FIT CUBIC SPLINE POLYNOMIALS TO DATA POINTS.

      CALL SPLINEPOLYFIT (PHI,PAS,A,B,C,D,NPOINTS)

C GENERATE X VALUES WHERE POLYNOMIAL IS TO BE EVALUATED FOR FURTHER
C  CALCULATIONS AND GRAPHS.

      RANGE = PHI(NPOINTS)-PHI(1)
      XI(1) = PHI(1)
      DO 11 I = 2,200
      XI(I) = XI(I-1) + RANGE/200.0
11    CONTINUE

C EVALUATE CUBIC SPLINE POLYNOMIAL AT ABSCISSAE XI(L).

      DO 12 L = 1,200
      YI(L)=SPLINEPOLY(PHI,PAS,A,B,C,D,XI(L),200)
12    CONTINUE

C SET UP VALUES OF PHI3, PHI5, ...., PHI95, PHI97 BY APPROXIMATING
C  TO VALUE CLOSEST TO REQUIRED PHI VALUE.

      DO 36 IJ=2,198,2
      KJ = (200-IJ)/2
      DO 37 JJ=1,200
      IF(YI(JJ).LE.KJ) GO TO 35
37    CONTINUE

C V(KJ) = PHI(KJ).

35    V(KJ) = XI(JJ)
```

```
36    CONTINUE

C CALCULATE MEANS, KURTOSIS, SORTING AND SKEWNESS BY VARIOUS METHODS.

C KURTOSIS:
C FOLK AND WARD

      GKFW = (V(95)-V(5))/(2.44*(V(75)-V(25)))

C MEANS
C FOLK AND WARD

      ZMFW = (V(16)+V(50)+V(84))/3.0

C MCCAMMON

      ZMMC = (V(5)+V(15)+V(25)+V(35)+V(45)+V(55)+V(65)+V(75)+
     *V(85)+V(95))/10.0

C SORTING:
C FOLK AND WARD

      SFFW = (V(84)-V(16))/4.0+(V(95)-V(5))/6.6
C MCCAMMON

      SFMC = (V(70)+V(80)+V(90)+V(97)-V(3)-V(10)-V(20)-V(30))/9.1

C SKEWNESS
C FOLK AND WARD

      SKFW = (V(84)+V(16)-2.0*V(50))/(2.0*(V(84)-V(16)))
     *+(V(95)+V(5)-2.0*V(50))/(2.0*(V(95)-V(5)))

      WRITE (6,21) LOCA,DATE
21    FORMAT (1H1,13H  LOCATION:  ,30A1,5X,7HDATE:  ,20A1,/)
      WRITE (6,22) SAMPLE,PROJ
22    FORMAT (1H ,15H  SAMPLE NO.:  ,10A1,5X,10HPROJECT:  ,30A1,/)
      WRITE (6,23) DESCN,OPER
23    FORMAT (1H ,15H  DESCRIPTION:  ,30A1,2X,11HOPERATER:  ,20A1)

C WRITE OUT SIEVING DATA.

      WRITE (6,102)
102   FORMAT (1H ,/,15H  SIEVING DATA:)
      WRITE (6,111) SUM
111   FORMAT (1H ,/,25H  TOTAL WEIGHT OF SAMPLE:,F8.3)
      WRITE (6,101)
101   FORMAT (1H ,/,2X,14HSIEVE PHI SIZE,5X,15HWEIGHT RETAINED,5X,
     *10H% RETAINED,5X,9H% PASSING,/)
      WRITE (6,113) (PHI(NN),WT(NN),RET(NN),PAS(NN),NN = 1,NPOINTS)
113   FORMAT (4X,F8.3,12X,F8.3,9X,F8.3,7X,F8.3)
      WRITE (6,99)

C WRITE OUT GRAPHICAL MOMENT PARAMETERS.

99    FORMAT (1H ,/,29H GRAPHICAL MOMENT PARAMETERS:,/)
      WRITE (6,89)
89    FORMAT (22H FOLK AND WARD VALUES:)
      WRITE (6,90) GKFW,ZMFW,SFFW,SKFW
90    FORMAT (12H KURTOSIS = ,F8.3,1X,7HMEAN = ,F8.3,1X,
     *10HSORTING = ,F8.3,1X,11HSKEWNESS = ,F8.3,/)
```

```
      WRITE (6,91)
91    FORMAT (17H MCCAMMON VALUES:)
      WRITE (6,92) ZMMC,SFMC
92    FORMAT (8H MEAN = ,F8.3,1X,10HSORTING = ,F8.3,/)
      WRITE(6,888)V(1),V(50),V(99)
  888 FORMAT(1H0,1X,3F10.3)

C PLOT GRAPHS OF CURVES;CROSSES MARK DATA POINTS, SOLID CURVE
C IS FITTED POLYNOMIAL.

      GO TO 999
      CALL AMGRAPH (6,0,200,0,4HAMDG,YI,XS,YS,H,0)
      CALL AMGRAPH (6,0,200,1,XI,YI,XS,YS,H,AMDG)
      CALL AMGRAPH (6,12,NPOINTS,1,PHI,PAS,XS,YS,H,AMDG)
      CALL AMGRAPH (6,0,200,2,XI,YI,XS,YS,H,AMDG)

C GO BACK TO READ MORE DATA.

  999 GO TO 5
40    CONTINUE
      CALL ENDGRAPH
      STOP
      END

C

C*********************************************************************A
C
      SUBROUTINE SPLINEPOLYFIT (X,F,A,B,C,D,M)

C GENERATES APPROPRIATE COEFFICIENTS A(J),B(J),C(J),D(J) J=1(1)M-1 FOR
C CUBIC SPLINE INTERPOLATION IN TABULATED FUNCTION X(J),F(J) J=1(1)M
C PARABOLAE FITTED IN END INTERVALS.

      DIMENSION X(M),F(M),A(M),B(M),C(M),D(M)
      MM1=M-1
      A(1)=X(2)-X(1)
      DO 10 I=2,MM1
      B(I)=A(I-1)
      A(I)=X(I+1)-X(I)
      D(I)=2.0*(A(I)+B(I))
10    C(I)=6.0*((F(I+1)-F(I))/A(I)-(F(I)-F(I-1))/B(I))
20    D(1)=1.0
      D(M)=1.0
      A(1)=-1.0
      B(M)=-1.0
      C(1)=-1.0
      C(M)=1.0
      DO 60 I=2,M
      R=B(I)/D(I-1)
      D(I)=D(I)-R*A(I-1)
60    C(I)=C(I)-R*C(I-1)
      C(M)=C(M)/D(M)
      DO 70 I=2,M
      J=M-I+1
70    C(J)=(C(J)-A(J)*C(J+1))/D(J)
      DO 80 I=1,MM1
      H=X(I+1)-X(I)
      A(I)=(C(I+1)-C(I))/(6.0*H)
      B(I)=0.5*C(I)
      C(I)=(F(I+1)-F(I))/H-(2.0*C(I)+C(I+1))*H/6.0
```

```
80     D(I)=F(I)
       RETURN
       END

       FUNCTION SPLINEPOLY (X,F,A,B,C,D,XS,M)

CEVALUATES CUBIC SPLINE INTERPOLATION FUNCTION AT ABSCISSA XS IN
C
CTABULATED FUNCTION X(J),F(J) J=1(1)M USING APPROPRIATE COEFFICIENTS
C A(J),B(J),C(J),D(J) J=1(1)M GENERATED IN PRIOR CALL TO ROUTINE
C POLYSPLINEFIT, ROUTINE BASED ON CONTE AND DE BOOR.

       DIMENSION X(M),F(M),A(M),B(M),C(M),D(M)
       DATA I / 1 /
       MM1=M-1
       DX=XS-X(I)
       IF (DX) 10,40,30
10     IF (I.EQ.1) GO TO 40
       I=I-1
       DX=XS-X(I)
       IF (DX.GE.0.0) GO TO 40
       GO TO 10
20     I=I+1
       DX=DDX
30     IF (I.EQ.MM1) GO TO 40
       DDX=XS-X(I+1)
       IF (DDX.GE.0.0) GO TO 20
40     SPLINEPOLY=((A(I)*DX+B(I))*DX+C(I))*DX+D(I)
       RETURN
       END

       FINISH
```

C.3. Example of Printout Where Sieve and Hydrometer Analysis Were Used.

```
 LOCATION:  HOWISONS POORT DAM                          DATE:  JUNE, 1978
 SAMPLE NO.:  LOR002          PROJECT:  SEDIMENT SURVEY
 DESCRIPTION:  RESERVOIR SEDIMENT                       OPERATER:  A.WEAVER.
SIEVING DATA:
TOTAL WEIGHT OF SAMPLE: 100.000
SIEVE PHI SIZE        WEIGHT RETAINED        % RETAINED        % PASSING

     0.250                 0.000               0.000            100.000
     1.000                 0.250               0.250             99.750
     2.200                 0.430               0.430             99.320
     3.000                 1.840               1.840             97.480
     4.000                10.270              10.270             87.210
     4.100                23.640              23.640             63.570
     4.500                10.840              10.840             52.730
     5.600                10.660              10.660             42.070
     6.000                13.120              13.120             28.950
     6.300                 7.790               7.790             21.160
     6.500                 4.920               4.920             16.240
     6.900                 4.510               4.510             11.730
     7.400                 1.230               1.230             10.500
     7.800                 0.460               0.460             10.040
     9.500                10.040              10.040              0.000
    10.000                 0.000               0.000              0.000
GRAPHICAL MOMENT PARAMETERS:

FOLK AND WARD VALUES:
KURTOSIS =      1.220 MEAN =     4.930 SORTING =    -1.967 SKEWNESS =    -0.660

MCCAMMON VALUES:
MEAN =      5.164 SORTING =    -1.618
   FINEST 1%     MEDIAN     COARSEST 1%
     9.269       4.199        0.640
```

C.4. Example of Printout Where Only a Sieve Analysis Was Used.

```
  LOCATION:                                             DATE:
  SAMPLE NO.:  LSRS07          PROJECT:
  DESCRIPTION:                                          OPERATER:
 SIEVING DATA:
 TOTAL WEIGHT OF SAMPLE:  61.900
 SIEVE PHI SIZE        WEIGHT RETAINED        % RETAINED        % PASSING

     -0.500                 0.000              0.000            100.000
      0.250                 0.170              0.275             99.725
      1.000                 0.810              1.309             98.417
      2.250                29.570             47.771             50.646
      3.000                24.330             39.305             11.341
      4.000                 5.360              8.659              2.682
      5.000                 1.660              2.682              0.000
      6.000                 0.000              0.000              0.000
 GRAPHICAL MOMENT PARAMETERS:

 FOLK AND WARD VALUES:
 KURTOSIS =      0.922 MEAN =     2.252 SORTING =    -0.643 SKEWNESS =     0.02

 MCCAMMON VALUES:
 MEAN =      2.256 SORTING =    -0.646
    FINEST 1%     MEDIAN     COARSEST 1%
      4.732       2.263        0.963
```

APPENDIX D.

CORRELATION

A correlation analysis was used to show statistically the general tendency of the data. Davis (1973) developed a computer program for a correlation analysis which is widely used by geologists and other earth scientists for cases where one variable is known and the other is distributed along this continuum. The method is therefore particularly useful in the present study where samples are taken along linear transects.

D.1. Description of the Computer Program.

Davis' program (D.3.) defines the regression line:

$$Y_i = b_o + b_1 H_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where Y_i = dependent variable

X_i = independent variable

Y_i = estimated values of Y_i; at specified values of X_i

b_o = point of X axis where line crosses

b_1 = slope of the line

Equation (1) defines the line from which the deviations are minimal. The variation of the dependent variable (Y) from the independent variable (X) is expressed in four ways:

a) The total number of squares (SSt) of Y:

$$SSt = \sum_{i=1}^{n} (Y_i - \bar{Y})^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

this quantity, divided by (n - 1) gives the variance of Y.

b) The sum of squares due to regression (SS_R)

$$SS_R = \sum_{i=2}^{n} (\hat{Y}_i - \bar{Y})^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

this value describes the variation of the regression line around the mean. If the estimated Y values ($\hat{Y}_i$) are equal to the measured Y values (Y_i), the sum of the squares calculated by (b) and (c) will be the same. If not, the sum of the squares due to regression will be smaller and there will be 'leftover' variation.

c) This 'leftover' is called the sum of squares due to deviations (SS_D):

$$SS_D = SS_t - SS_R \quad \ldots\ldots \quad (4)$$

d) A useful measure of the strength of the linear relationship between the two variables is the correlation coefficient. The correlation coefficient is the square root of the "goodness of fit" (R^2), which is defined as:

$$R^2 = \frac{SS_R}{SS_t} \quad \ldots\ldots \quad (5)$$

The correlation coefficient (R) is defined as:

$$R = \sqrt{SS_R/SSt} \quad \ldots\ldots \quad (6)$$

The correlation coefficient reflects the "...degree to which changes in one direction and magnitude in one set of data are associated with comparable changes in the other set." (Gregory, 1963, p. 189). The correlation coefficient is a dimensionless number which ranges between + 1 and - 1. + 1 indicating a perfect direct relationship between the two variables; - 1 indicating an indirect relationship between the two variables.

A typical printout from the present study is presented in D.4.

D.2. Level of Significance of the Relationships.

In order to prevent the rejection of a correct hypothesis, the probability of this type of error (type 1 error) is calculated. The probability of commiting a type 1 error is set before the running of the test. The probability set for the present study is 5%; this figure is arbitrarily chosen using previous workers' experience as a guideline. The method of calculation used in determining the level of significance of the relationship is known as the Students t - test and is expressed as:

$$t = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}}$$

where, r = correlation coefficient

n - 2 = degrees of freedom.

The critical values for t at various significant levels was read off from the graph depicted in figure D.1.

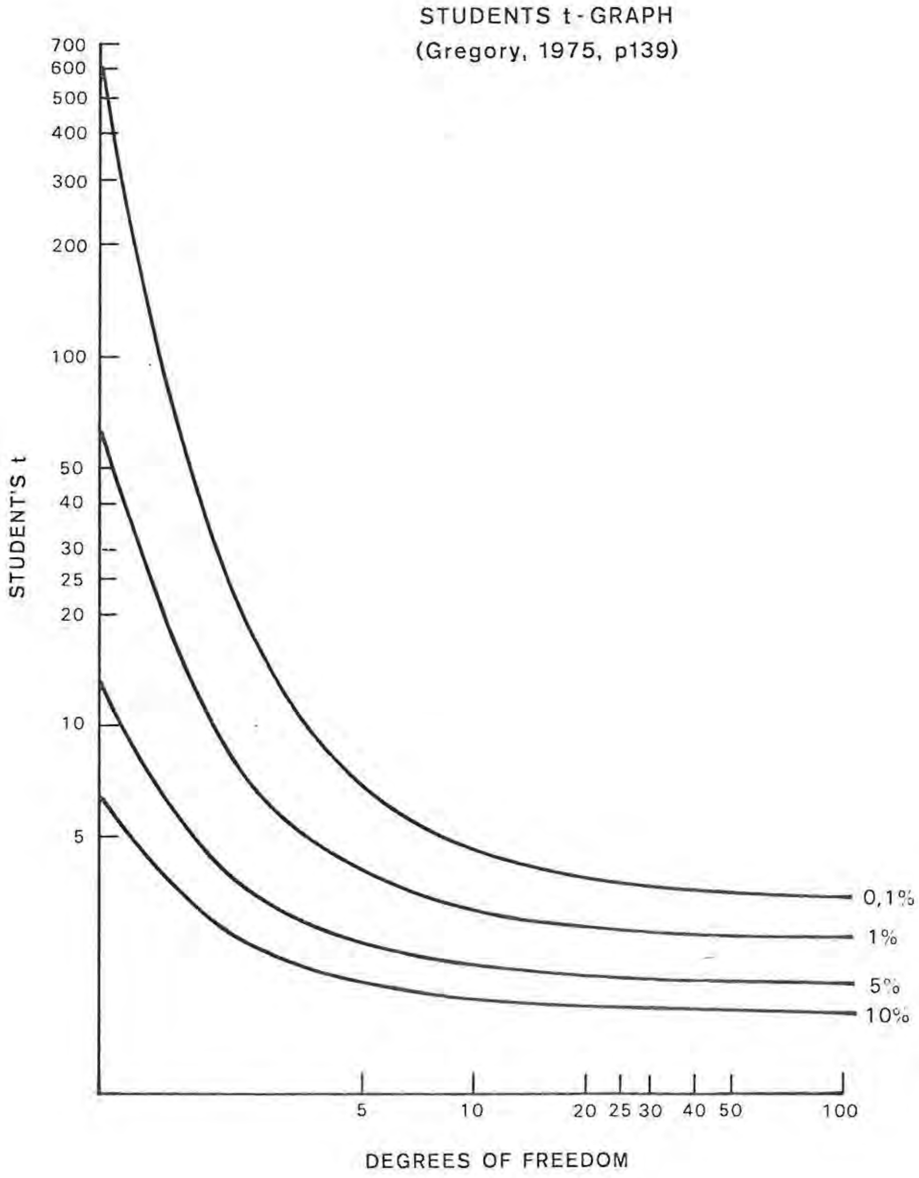

STUDENTS t-GRAPH
(Gregory, 1975, p139)

Figure D.1.

D.3. Program Used for Correlation Analysis

```
----------------------------------------------------------------------------------
        DATE 19/12/78   TIME 14/30/19                          LISTING FOR:- G

FILE:   GGAWMAXIMOP     SUBFILE CORE IN CARD MODE

      LIST
      PROGRAM(CORE)
      INPUT 5=CR0
      OUTPUT 6=LP0
      TRACE 2
      END
      MASTER CORE
C     PROGRAM 5-3
C     ROUTINE LINFIT
C
C     PROGRAM TO FIT A LINEAR REGRESSION.
C
C     ARRAY A CONTAINS X AND Y DATA THAT IS READ IN.
C     ARRAY B CONTAINS THE COEFFICIENTS OF THE UNKNOWN B'S IN THE
C     NORMAL EQUATIONS 5.7 AND 5.8.
C     ARRAY C ORIGINALLY IS A VECTOR THAT CONTAINS THE SUM OF THE Y'S
C     AND THE SUMS OF THE CROSSPRODUCTS OF X AND Y IN EQUATION 5.11.
C     AFTER THE NORMAL EQUATIONS ARE SOLVED, ARRAY C CONTAINS THE
C     COEFFICIENTS OF THE REGPESSION EQUATION.
C     SUMS OF THE CROSSPRODUCTS OF X AND Y IN EQUATION 5.11.
C     ARRAY D CONTAINS X, Y, Y-CALCULATED, AND DEVIATIONS FOR ALL
      DATA POINTS.
C
C     THE MAXIMUM NUMBER OF OBSERVATIONS IS 100.
C
C     SUBROUTINES NEEDED ARE READM, PRINTM, AND SLE.
C     ==============================================================
C
      DIMENSION A(100,2),B(2,2),C(2),D(100,4)
C
C     READ X-Y DATA AND PRINT IT OUT.
C
      CALL READM(A,N,M,100,2)
      CALL PRINTM(A,N,M,100,2)
C
C     CALCULATE SUMS FOR LEAST SQUARES SOLUTION
C
      DO 100 I=1,2
      C(I)=0.0
      DO 101 J=1,2
      B(I,J)=0.0
  101 CONTINUE
  100 CONTINUE
      DO 102 I=1,N
      B(1,1)=B(1,1)+1.0
      B(1,2)=B(1,2)+A(I,1)
      B(2,2)=B(2,2)+A(I,1)*A(I,1)
      C(1)=C(1)+A(I,2)
      C(2)=C(2)+A(I,1)*A(I,2)
  102 CONTINUE
      B(2,1)=B(1,2)
C
C     SOLVE THE SIMULTANEOUS LINEAR EQUATIONS WHICH ARE OF THE FORM
C     OF 5.7 AND 5.8 IN THE TEXT.
C
      CALL PRINTM(B,2,2,2,2)
```

```
      WRITE(6,1001)
      CALL PRINTM(C,1,2,1,2)
      WRITE(6,1002)
      CALL SLE(B,C,2,2,1.0E-05)
      CALL PRINTM(C,1,2,1,2)
      WRITE (6,1003)
      DO 103 I=1,N
      D(I,1)=A(I,1)
      D(I,2)=A(I,2)
      D(I,3)=C(1)+C(2)*D(I,1)
      D(I,4)=D(I,2)-D(I,3)
  103 CONTINUE
      CALL PRINTM(D,N,4,100,4)
      WRITE(6,1004)
C
C     CALCULATE ERROR MEASURES
C
      SY=0.0
      SY2=0.0
      SYC=0.0
      SYC2=0.0
      DO 104 I=1,N
      SY=SY+D(I,2)
      SY2=SY2+D(I,2)*D(I,2)
      SYC=SYC+D(I,3)
      SYC2=SYC2+D(I,3)*D(I,3)
  104 CONTINUE
      SST=SY2-SY*SY/FLOAT(N)
      SSR=SYC2-SYC*SYC/FLOAT(N)
      SSD=SST-SSR
      R2=SSR/SST
      R=SQRT(R2)
      WRITE (6,1990)
      WRITE (6,2000) N
      WRITE (6,2001) SST
      WRITE (6,2002) SSR
      WRITE (6,2003) SSD
      WRITE (6,2004) R2
      WRITE (6,2005) R
      STOP
 1001 FORMAT(1H0,1X,43HCOEF.MATRIX OF UNKNOWN PARAMETERS IN NORMAL EQNS)
 1002 FORMAT(1H0,1X,34HVECTOR OF CROSSPRODUCTS OF X AND Y)
 1003 FORMAT(1H0,1X,41HTHE PARAMETERS OF THE REGRESSION EQUATION)
 1004 FORMAT(1H0,1X,16HCOL 1=X VARIABLE,/,1X,16HCOL 2=Y VARIABLE,/,
     1 1X,37HCOL 3=Y VALUE BASED ON REGRESSION EQN,/,1X,
     2 17HCOL 4=COL 2-COL 3)
 1990 FORMAT(1H1)
 2000 FORMAT(21H0NUMBER OF SAMPLES = ,I5)
 2001 FORMAT(25H0TOTAL SUMS OF SQUARES = ,F15.4)
 2002 FORMAT(37H0SUMS OF SQUARES DUE TO REGRESSION = ,F15.4)
 2003 FORMAT(36H0SUMS OF SQUARES DUE TO DEVIATION = ,F15.4)
 2004 FORMAT(19H0GOODNESS OF FIT = ,F15.6)
 2005 FORMAT(27H0CORRELATION COEFFICIENT = ,F15.6)
      END
C
C     PROGRAM 4 - 1
C
C     SUBROUTINE TO READ A MATRIX
C     HAVING N ROWS AND M COLUMNS
C
      SUBROUTINE READM(A,N,M,N1,M1)
```

```
      DIMENSION A(N1,M1)
C     READ SIZE OF MATRIX
      READ (5,1000) N,M
C     READ MATRIX ONE ROW AT A TIME
      DO 100 I=1,N
      READ (5,1001) (A(I,J),J=1,M)
  100 CONTINUE
      RETURN
 1000 FORMAT (2I3)
 1001 FORMAT (2F8.2)
      END
C
C     PROGRAM 4 - 2
C
C     SUBROUTINE TO PRINT A MATRIX
C     HAVING N ROWS AND M COLUMNS
C
      SUBROUTINE PRINTM(A,N,M,N1,M1)
      DIMENSION A(N1,M1)
C     PRINT MATRIX OUT IN STRIPS OF 10 COLUMNS
      DO 100 IB=1,M,10
      IE=IB+9
      IF (IE-M) 2,2,1
    1 IE=M
C     PRINT HEADING
    2 WRITE (6,2000) (I,I=IB,IE)
      DO 101 J=1,N
C     PRINT ROW OF MATRIX
      WRITE (6,2001) J,(A(J,K),K=IB,IE)
  101 CONTINUE
  100 CONTINUE
      RETURN
 2000 FORMAT (1H1,1X,10I12)
 2001 FORMAT (1H0,I5,10F12.4)
      END
C
C     PROGRAM 4 - 9
C
C     SUBROUTINE FOR SOLUTION OF N SIMULTANEOUS EQUATIONS.
C     MATRIX A IS N X N AND B IS A COLUMN VECTOR OF N ELEMENTS.
C     A IS CONVERTED TO THE IDENTITY MATRIX.
C     B CONTAINS SOLUTION.
C
      SUBROUTINE SLE(A,B,N,N1,ZERO)
      DIMENSION A(N1,N1),B(N1)
      DO 100 I=1,N
      DIV=A(I,I)
      IF (ABS(DIV)-ZERO) 99,99,1
    1 DO 101 J=1,N
      A(I,J)=A(I,J)/DIV
  101 CONTINUE
      B(I)=B(I)/DIV
      DO 102 J=1,N
      IF (I-J) 2,102,2
    2 RATIO=A(J,I)
      DO 103 K=1,N
      A(J,K)=A(J,K)-RATIO*A(I,K)
  103 CONTINUE
      B(J)=B(J)-RATIO*B(I)
  102 CONTINUE
  100 CONTINUE
```

```
      RETURN
   99 STOP
      END
      FINISH
```

D.4. Example of Printout for Correlation Analysis Correlating Mean Grain Size and the Distance to the Main Stream.

```
------------------------------------------------------------------------------------------
        DATE 19/12/78   TIME 14/37/29                                  LISTING FOR:- GG

FILE:   GGAWMAXIMOP      SUBFILE MAMZ IN CARD MODE

             1              2
   1      16.8000        1.8700
   2      28.8000        1.7800
   3      84.0000        1.9000
   4     158.4000        5.7900
   5     261.7000        4.9800
   6     255.7000        5.5600
   7     260.5000        5.6300
   8     357.7000        5.5600
   9     348.1000        5.8700
  10     345.7000        4.9300
  11     463.3000        6.4900
  12     462.0000        5.8200
  13     459.7000        5.9900
  14     462.1000        6.4100
  15     698.6000        6.2200
  16     654.2000        6.6800
  17     561.7000        6.5600
  18     600.2000        6.1700
  19     629.0000        6.4600
  20     624.2000        6.5900
  21     621.8000        6.1800
  22     924.2000        8.2900
  23     624.2000        6.0300
  24     763.4000        7.8900
  25     762.2000        7.3100
  26     930.2000        7.0100
  27     780.2000        6.8100
  28     806.6000        7.4400
  29     827.0000        7.0200
  30     841.4000        6.0200
  31     842.2000        7.2500
  32     925.4000        6.8700
  33     924.2000        7.5700
  34     344.5000        5.9100
  35     932.2000        6.5800
  36    1082.9000        6.9300
  37    1092.3000        5.2500
  38     624.2000        6.7100
  39     669.8000        7.0800
  40     566.5000        6.3900
  41    1068.0000        7.0500
  42    1089.6000        7.2500
  43    1110.0000        7.2200
  44    1093.3000        7.1600
  45     746.4000        7.3800
  46      48.0000        3.2300
  47      81.6000        2.5600
  48     114.0000        2.2500
             1              2
   1      48.0000   28969.2000
   2   28969.2000*22412091.8201
 COEF.MATRIX OF UNKNOWN PARAMETERS IN NORMAL EQNS
             1              2
   1     287.9000 193170.5960
 VECTOR OF CROSSPRODUCTS OF X AND Y
```

```
             1                2
   1      3.6203          0.0039
 THE PARAMETERS OF THE REGRESSION EQUATION
             1                2                3                4
   1     16.8000          1.8700           3.6865          -1.8165
   2     28.8000          1.7800           3.7338          -1.9538
   3     84.0000          1.9000           3.9512          -2.0512
   4    158.4000          5.7900           4.2443           1.5457
   5    261.7000          4.9800           4.6513           0.3287
   6    255.7000          5.5600           4.6277           0.9323
   7    260.5000          5.6300           4.6466           0.9834
   8    357.7000          5.5600           5.0295           0.5305
   9    348.1000          5.8700           4.9917           0.8783
  10    345.7000          4.9300           4.9822          -0.0522
  11    463.3000          6.4900           5.4455           1.0445
  12    462.0000          5.8200           5.4404           0.3796
  13    459.7000          5.9900           5.4313           0.5587
  14    462.1000          6.4100           5.4408           0.9692
  15    698.6000          6.2200           6.3725          -0.1525
  16    654.2000          6.6800           6.1976           0.4824
  17    561.7000          6.5600           5.8331           0.7269
  18    600.2000          6.1700           5.9848           0.1852
  19    629.0000          6.4600           6.0983           0.3617
  20    624.2000          6.5900           6.0794           0.5106
  21    621.8000          6.1800           6.0699           0.1101
  22    924.2000          8.2900           7.2612           1.0288
  23    624.2000          6.0300           6.0794          -0.0494
  24    763.4000          7.8900           6.6277           1.2623
  25    762.2000          7.3100           6.6230           0.6870
  26    930.2000          7.0100           7.2849          -0.2749
  27    780.2000          6.8100           6.6939           0.1161
  28    806.6000          7.4400           6.7979           0.6421
  29    827.0000          7.0200           6.8783           0.1417
  30    841.4000          6.0200           6.9350          -0.9150
  31    842.2000          7.2500           6.9382           0.3118
  32    925.4000          6.8700           7.2659          -0.3959
  33    924.2000          7.5700           7.2612           0.3088
  34    344.5000          5.9100           4.9775           0.9325
  35    932.2000          6.5800           7.2927          -0.7127
  36   1082.9000          6.9300           7.8864          -0.9564
  37   1092.3000          5.2500           7.9235          -2.6735
  38    624.2000          6.7100           6.0794           0.6306
  39    669.3000          7.0800           6.2590           0.8210
  40    566.5000          6.3900           5.8521           0.5379
  41   1068.0000          7.0500           7.8277          -0.7777
  42   1089.6000          7.2500           7.9128          -0.6628
  43   1110.0000          7.2200           7.9932          -0.7732
  44   1093.8000          7.1600           7.9294          -0.7694
  45    746.4000          7.3800           6.5608           0.8192
  46     48.0000          3.2300           3.8094          -0.5794
  47     81.6000          2.5600           3.9418          -1.3818
  48    114.0000          2.2500           4.0694          -1.8194
 COL 1=X VARIABLE
 COL 2=Y VARIABLE
 COL 3=Y VALUE BASED ON REGRESSION EQN
 COL 4=COL 2-COL 3

 NUMBER OF SAMPLES =      48
 TOTAL SUMS OF SQUARES =              121.0066
 SUMS OF SQUARES DUE TO REGRESSION =                 76.4887
 SUMS OF SQUARES DUE TO DEVIATION =                  44.5179
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GOODNESS OF FIT =          0.632104
CORRELATION COEFFICIENT =          0.795050
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