# AVAILABILITY OF BOREHOLE SYSTEMS FOR POTABLE WATER SUPPLY

(A Case Study of Selected States in the Crystalline Groundwater Province of Nigeria.)

By

MBAMALI, Ikemefuna

Being a dissertation submitted to the Postgraduate School of Ahmadu Bello University, Zaria, in partial fulfilment of the requirement for the award of the Doctor of Philosophy (Ph.D) degree in Building, Faculty of Environmental Design, Ahmadu Bello University, Zaria, Nigeria.

Dedicated

To

CHIAZOR AND OKWUOLISA

Declaration

I hereby declare that this dissertation is prepared by me and that it is a record of my own personal research work. It has not been presented in any previous application for a higher degree. All sources of information are specifically acknowledged by means of references.

26/11/97

## Certification

This dissertation/research work entitled:
"Availability of Borehole Systems For Potable Water Supply (A Case Study of Some Selected States in the Crystalline Groundwater Province of Nigeria)" by MBAMALI, Ikemefuna meets the regulations governing the award of the degree of Doctor of Philosophy (Ph.D) Building of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

| | |
|---|---|
| Chairman, Supervisory Committee | 27-11-97<br>Date |
| Member, Supervisory Committee | 27-11-97<br>Date |
| Head, Department of Building | 28.11.1997<br>Date |
| Dean, Postgraduate School | 12/6/98<br>Date |

Acknowledgement

I wish to thank some people who have contributed so much to the realisation of this work. Special thanks therefore go to: Professor T.O. Mosaku and Dr. A. Onugba my supervisors, for their guidance and scholarly inputs; Professors K.A. Wahab and R. Costa, the Directors of the Nigerian-Italian Ph.D Programme in Building Technology and Design, for the direction and exposure to modern library facilities which they offered me at the inception of this work.

Equally appreciated is Mr Z.J. Sikora the Head of Building Department of Ahmadu Bello Univeristy, Zaria; under whose effectual administration the work was carried out.

I am also grateful to some staff members of the "UNICEF WATSAN Projects" - the Project Manager North-Western Zone, The Project Managers of Niger, Kaduna and Kwara States - who gave me access to their borehole project records. My gratitude also extends to Messrs Sani Mahmu and Jibrin Mohammed, both of WRECA Kano; as well as to Mr Soba Kasimo, the Head of Rural Water Supply Department of Soba Local Government Zaria; who also assisted me with their borehole project records.

Mention must also be made of the contributions and assistance I received from staff members of the Department: Mr Haruna the Computer Operator who diligently typed out the work, Mr Richifa who traced out most of the diagrams, Dr Okoli, Messrs Kehinde, I.K. Zubairu, K. Bala; my able colleagues whose cooperation and moral

support I enjoyed all through.

Most of all, I am grateful to God almighty who granted me the health, strength and grace to go through it all.

## Abstract

The work articulates borehole systems definition and project criteria, as systems evaluation principles. These serve as background knowledge for the assessment of availability of handpump-equipped boreholes in the Crystalline Groundwater Province of Northern Nigeria.

The study which is mainly based on project files and performance records, draws samples of a hundred boreholes from each of four states (Kaduna, Kano, Kwara and Niger States) within the area of interest. Also assessed are such related measures of systems effectiveness as: reliability, maintainability, failure patterns and frequencies, times to first failure, up-times and down-times of the boreholes.

The study shows that there are no significant differences in the respective values of these parameters, in the four states. Availability as a measure of the up-times of the boreholes over the initial five-year period of their operation is found satisfactory. However, as a measure of the probability for adequate performance over the designed life of the boreholes, with no down-times in excess of one week; availability is found problematic as from the fourth year of operation of the boreholes. The handpump sub-system shows a much higher failure frequency - 88% approx.of the system failure - than the well. This in turn is accounted for mainly by the cylinder assembly, riser pipe and head assembly components; with 41%, 22%, 12% approx. of the system failure respectively.

Suggestions made for improving the availability include:

improving the inherent reliablity of the handpump, closer monitoring of the borehole systems in operation to ensure timely failure identification and reporting, keeping adequate stock of spares and swift mobilisation of resources for repair work.

TABLE OF CONTENTS


| | | Page |
|---|---|---|
| | Title Page | i |
| | Dedication | ii |
| | Declaration | iii |
| | Certification | iv |
| | Acknowledgements | v |
| | Abstract | vii |
| | Table of Contents | ix |
| | List of Tables | xv |
| | List of Figures and Plates | xviii |
| | List of Appendices | xx |
| | Acronyms and Notations | xxi |
| CHAPTER ONE | INTRODUCTION | |
| 1.0 | Background | 1 |
| 1.1 | Need For The Work | 2 |
| 1.2 | Aims and Objectives | 4 |
| 1.3 | Methodology | 4 |
| 1.4 | Scope and Limitations of the Study | 6 |
| CHAPTER TWO | RURAL WATER SUPPLY BOREHOLE SYSTEMS DEFINITION AND THEIR ENVIRONMENT OF OPERATION | |
| 2.0 | Systems Concept | 7 |
| 2.1 | Boreholes | 7 |
| 2.1.1 | Types of Boreholes | 8 |

| | | |
|---|---|---|
| 2.1.2 | Design and Construction of Boreholes | 10 |
| 2.1.3 | Yield of Boreholes | 13 |
| 2.1.4 | Borehole Water Quality | 14 |
| 2.2 | Pumps | 17 |
| 2.2.1 | Handpumps - Types of Components | 27 |
| 2.2.2 | Pump Reliability and Maintenance | 33 |
| 2.2.3 | Pump Selection Criteria | 34 |
| 2.3 | Borehole Failures | 34 |
| 2.3.1 | Well Failure and Rehabilitation | 36 |
| 2.3.2 | Handpump Failure and Maintenance | 38 |
| 2.4 | Rural Borehole Maintenance Organisation Systems | 40 |
| 2.5 | Socio-Economic Characteristics of Nigeria's Rural Communities And The Crystalline Groundwater Provinces | 42 |
| 2.5.1 | Socio-Economic Characteristics | 42 |
| 2.5.2 | The Groundwater Provinces of Nigeria | 43 |
| 2.5.3 | The Crystalline Groundwater Province | 42 |
| CHAPTER THREE | SYSTEMS ANALYSIS CONCEPTS | |
| 3.0 | Systems Ananlysis Definition | 46 |
| 3.1 | Systems Evaluation | 46 |
| 3.1.1 | Purposes of Systems Evaluation | 47 |
| 3.2 | Measures of Systems Effectiveness | 47 |
| 3.3 | Reliability | 48 |
| 3.3.1 | Inherent and Use Reliability | 49 |

| | | |
|---|---|---|
| 3.3.2 | Series and Parallel Reliability | 50 |
| 3.3.3 | Reliability Prediction | 52 |
| 3.3.4 | Gathering Reliability Data | 54 |
| 3.3.5 | Common Measures of Reliability | 55 |
| 3.4 | Maintainability | 55 |
| 3.4.1 | Nature and Importance of Maintainability | 56 |
| 3.4.2 | Factors Affecting maintainability | 57 |
| 3.4.3 | Maintainability Equation | 58 |
| 3.4.4 | Maintainability Increment | 58 |
| 3.5 | Availability | 59 |
| 3.5.1 | Equipment Availability Models | 60 |
| 3.5.2 | Availability Prediction | 63 |
| 3.5.3 | Availability Standards | 64 |

CHAPTER FOUR FIELD DATA COLLECTION AND PRESENTATION

| | | |
|---|---|---|
| 4.0 | Background | 65 |
| 4.1 | Questionaire Distribution | 65 |
| 4.2 | Data Presentation | 65 |
| 4.2.1 | Maintenance Time Constraint | 66 |
| 4.2.2 | Shut-Down Time For Routine Maintenance | 66 |
| 4.2.3 | Failure Frequency | 67 |
| 4.2.4 | Probability of Survival Computation | 69 |
| 4.2.5 | Maintainability and Maintainability Increment Computation and Results | 70 |
| 4.2.6 | Availability Computation and Results | 71 |

| | | |
|---|---|---|
| 4.2.7 | Down-Times and Repair Times For The Failed Borehole Units | 72 |
| 4.2.8 | Up-Time Ratios For The Failed Borehole Units | 75 |
| 4.2.9 | Times To First Failure - Summary of Results For The Four States | 76 |
| CHAPTER FIVE | FIELD DATA ANALYSIS | |
| 5.0 | Data Analysis Concepts | 77 |
| 5.1 | Failure Frequencies | 77 |
| 5.1.1 | Component Failure Frequency | 77 |
| 5.1.2 | Sub-System Failure Frequency | 78 |
| 5.1.3 | System Failure Frequency | 79 |
| 5.2 | Probability of Survival | 80 |
| 5.2.1 | Probability of Survival in Each of The Four States | 80 |
| 5.2.2 | Modeling The Probability of Survival | 81 |
| 5.2.3 | Probability of Survival Prediction Over The 20-Year Assumed Design Life The Handpump-Equipped Borehole | 85 |
| 5.3 | Maintainability and Maintainability Increment | 87 |
| 5.3.1 | Maintainability | 87 |
| 5.3.2 | Maintainability Increment | 88 |

| | | |
|---|---|---|
| 5.4 | Availability | 89 |
| 5.4.1 | Availability in The Four States | 89 |
| 5.4.2 | Availability Prediction Over The 20-Year Assumed Life of The Handpump-Equipped Borehole | 90 |
| 5.5 | Down-Times And Repair Times | 94 |
| 5.5.1 | Total Down-Times (Weeks) For The Failed Borehole Units | 94 |
| 5.5.2 | Total Repair Times (Hours) For The Failed Borehole Units | 94 |
| 5.6 | Up-Time Ratios And Time To First Failure | 96 |
| 5.6.1 | Up-Time Ratios For The Failed Boreholes | 96 |
| 5.6.2 | Times To First Failure For The Failed Borehole Units | 97 |
| 5.7 | Summary of Results | 98 |
| 5.8 | Discussion | 99 |
| 5.8.1 | Reliability of The Field Investigation Data | 99 |
| 5.8.2 | Constant Failure Rate | 100 |
| 5.8.3 | Availability Results | 100 |
| 5.8.4 | Criteria For Improving The Availability of The Handpump-Equipped Boreholes | 101 |
| CHAPTER SIX | CONCLUSION AND RECOMMENDATION | |
| 6.1 | Conclusiom | 103 |
| 6.2 | Recommendations | 104 |

6.2.1 Suggestions For Improving The Availability of The Boreholes 104
6.2.2 Suggestions For Obtaining Reliable Field Data For Borehole Availability Evaluation 106
6.2.3 Areas of Further Research. 108

## LIST OF TABLES


| TABLE | | PAGE |
|---|---|---|
| 2.1 | Information on Types of Pumps | 29 |
| 2.2 | Performance Indices on Types of India Mark II Handpumps | 33 |
| 2.3 | Selection Criteria of Handpumps For Rural Water Supply | 35 |
| 2.4 | Nature, Causes and Remedy For Common India Mark II Handpump Problems | 39 |
| 4.1 | Maintenance Time Constraint | 66 |
| 4.2 | Shut-Down Times For Routine Maintenance | 66 |
| 4.3 | Component Failure Frequency | 67 |
| 4.4 | Sub-System Failure Frequency | 67 |
| 4.5 | System failure Frequency | 69 |
| 4.6 | Probability of Survival For The 100 Boreholes in State A | 69 |
| 4.7 | Probability of Survival Results For The Four States | 70 |
| 4.8 | Maintainability/Maintainability Increment For The Boreholes in State A | 70 |
| 4.9 | Maintainability Results For The Four States | 71 |
| 4.10 | Maintainability Increment Results For The Four States | 71 |
| 4.11 | Availability of The Boreholes in State A | 72 |
| 4.12 | Availability Results For The Four States | 72 |

| | | |
|---|---|---|
| 4.13 | Total Down-Times: Summary of Results For The Four States | 75 |
| 4.14 | Total Repair Times: Summary Of Results For The Four States | 75 |
| 4.15 | Up-Time ratio - Summary Of Results For The Four States | 76 |
| 4.16 | Time To First Failure - Summary Of Results For The Four States | 76 |
| 5.1 | One-Way ANOVA For The Component Failure Frequency Results of Table 4.3 | 78 |
| 5.2 | One-Way ANOVA For The Sub-System Failure Frequency Results of Table 4.4 | 79 |
| 5.3 | Chi-Square Computation For The System Failure Frequency | 80 |
| 5.4 | One-Way ANOVA For The Probability of Survival Result of Table 4.7 | 81 |
| 5.5 | Curve Fitting Computations For The Probability of Survival Data of table 4.7 | 84 |
| 5.6 | Predicted Values of Probability Survival Over A 20-Year Time Period | 85 |
| 5.7 | Two-Way ANOVA For The Maintainability Results of Table 4.9 | 87 |
| 5.8 | One-Way ANOVA For The Maintainability Increment Results of Table 4.10 | 89 |
| 5.9 | One-Way ANOVA For The Availability Results of Table 4.12 | 90 |

| | | |
|---|---|---|
| 5.10 | Predicted values of Availability Over A 20-Year Time Period | 91 |
| 5.11 | One-way ANOVA For The Total Down-Time Results of Table 4.13 | 94 |
| 5.12 | One-way ANOVA For The Total Repair-Time Results of Table 4.14 | 95 |
| 5.13 | One-Way ANOVA For The Total Up-Time Ratio Results of Table 4.15 | 96 |
| 5.14 | One-Way ANOVA For The Times To First Failure Results of Table 4.16 | 97 |
| 6.1 | Check List of Necessary Reliability And Maintainability Information | 106 |

## LIST OF FIGURES AND PLATES


| FIGURE | | PAGE |
|---|---|---|
| 2.1 | Parts of a Borehole | 9 |
| 2.2 | Typical Mechanised Borehole | 11 |
| 2.3 | Boreholes and Water Table In A Groundwater Reservoir | 16 |
| 2.4 | Sanitary Protection of Upper Terminal of Borehole | 18 |
| 2.5 | Suction Pump (Shallow Well) | 21 |
| 2.6 | Lift Pump (Deep Well) | 22 |
| 2.7 | Force Pumps | 23 |
| 2.8 | Rotary Pumps | 24 |
| 2.9 | Axial Flow Pump | 26 |
| 2.10 | Centrifugal Pump With Volute-Type Casing | 26 |
| 2.11 | Air-Lift Pump | 28 |
| 2.12 | Sectional Details of Above Ground Components of India Mark II Handpump | 31 |
| 2.13 | Cylinder Assembly of India Mark II Handpump | 30 |
| 2.14 | Sectional Details of Above Ground Components of India Mark III Handpump | 31 |
| 2.15 | Cylinder Assembly of India Mark III Handpump | 32 |
| 3.1 | Functional Diagrams | 53 |
| 3.2 | Relationship Between Availability, Maintainability and Probability of Survival | 61 |
| 4.1 | Comparative Sub-System Failure Histogram | 68 |
| 4.2 | Comparative System Failure Histogram | 68 |

| | | |
|---|---|---|
| 4.3 | Availability and Probability of Survival Curves For State A | 73 |
| 4.4 | Availability and Probability of Survival Curves For State B | 73 |
| 4.5 | Availability and Probability of Survival Curves For State C | 74 |
| 4.6 | Availability and Probability of Survival Curves For State D | 74 |
| 5.1 | Best Fit Line For The Probability of Survival Results In The Four States | 83 |
| 5.2 | Estimated Values of Probability of Survival Over A 20-Year Time Period | 86 |
| 5.3 | Predicted Values of Availability Over A 20-Year Time Period | 92 |
| 5.4 | Predicted Availability, Maintainability and Probability of Survival Curves | 93 |

**PLATE**

| | | |
|---|---|---|
| 2.1 | Handpump-Equipped Borehole | 12 |
| 2.2 | Handpump-Equipped Borehole | 12 |

## LIST OF APPENDICES


| APPENDIX | | PAGE |
|---|---|---|
| A: | Questionaire 'Form A' | 112 |
| B: | Questionaire 'Form B' | 114 |
| C: | Sample of Initial Collection of Failure Data From The Questionaire | 117 |
| D: | Procedure For The Analysis of Variance | 124 |

## LIST OF ACRONYMS AND NOTATIONS

### ACRONYMS

| | |
|---|---|
| ANOVA | Analysis of Variance |
| C.I. | Confidence Interval |
| **df** | Degree of freedom |
| **SS** | Sum of Squares Total |
| SST | Sum of Squares Treatment |
| SSB | Sum of Squares Between Blocks |
| SSE | Sum of Squares for Errors |
| UTR | Up-Time Ratio |
| DTR | Down-Time Ratio |

### NOTATIONS

| | |
|---|---|
| **A** | Availability |
| $\mathbf{A_E}$ | Equipment Availability |
| **C** | Correction factor |
| **e** | Base of Napierien or natural logrithm |
| $\mathbf{e_i}$ | Expected frequency |
| **H** | Level of original water table |
| **h** | Final level in the borehole |
| **K** | Permeability (mm/sec) |
| **k** | Number of categories or number of columns |
| **M** | Maintainability |
| $\mathbf{M_\Delta}$ | maintainability Increment |
| **m** | Mean time between failures |
| **n** | Number of rows |
| $\mathbf{O_i}$ | Observed frequency |

| | |
|---|---|
| $P$ | Component reliability |
| $P_c$ | System reliability for a specified period of time |
| $P_f$ | Probability of failure |
| $P_s$ | Probability of survival |
| $Q$ | Yield of borehole |
| $r$ | Failure rate |
| $2r$ | Diameter of borehole |
| $2R$ | Radius of influence |
| $S$ | Standard deviation |
| $t$ | Maintenance time constraint |
| $T$ | Total observation time of test period |
| $T_i$ | Sum of the ith row |
| $T_j$ | Sum of the jth row |
| $u$ | Mean time of maintenance action |
| $U$ | System unreliability |
| $V$ | Degree of freedom |
| $X$ | Mean |
| $x_i$ | Mean of the ith row |
| $X_i$ | Mean of the jth row |
| $x_{ij}$ | The observation in the ith row and jth column |

# CHAPTER ONE

# INTRODUCTION

## 1.0 BACKGROUND.

Water is important to virtually all processes in life. For both urban and rural communities therefore, water supply for domestic, agricultural, health and sanitation, commercial and industrial purposes, is a very essential service an undue interruption of which may cause a lot of adverse social, health and economic consequencies.

Large centralised water supply systems are usually employed for urban communities while simple isolated systems are usually adopted for rural cmmuunities especially of the developing countries. The supply source for both urban and rural water supply may be surface ( pond, lake, stream, river) or underground (spring or deep well) or a combination of both. One of the basic requirements for any water supply system is the delivery of water at all necessary times in the correct quality and quantity specifications. The desire to achieve this (as well as other requirements for the systems), in the most cost efficient way had often propeled most Water Supply Agencies into research aimed at improving the performance of their systems.

One of the basic steps towards the improvement of a physical system is the evaluation of the performance of such a system already in operation, and the utilisation of information so derived, in the design, construction and operation of new ones. There are several measures of systems' performance but these can be categorised as economic, technical or social. Availability is a measure of system's performance that comes under the technical

the Federal, most states and local governments since 1986. Huge sum of money has therefore been going into water supply systems and from projections there should be over thirty thousand handpump - equipped boreholes serving various rural communities in the country today - Donaldson and Karim (1988,p.2).

Available reports on these projects however suggest some functioning problems. For example, frequent failure of the galvanised iron riser pipes (one of the components of the handpump) is known to have forced UNICEF to change all riser pipes in the Imo State Water and Sanitation (WATSAN) Project to PVC pipes in 1984. However PVC also failed and was subsequently substituted with stainless steel pipes in 1986 - Donaldson and Karim (1988, p.8). Furthermore, a cursory assessment made of the 634 boreholes installed in Kwara State between 1984 and 1993, under the UNICEF Assisted WATSAN Project, showed that about 150 of the boreholes were not in good operational condition due to either well or pump failure - Anonymous (1995). Also to be added to the above reports are the frequent out-cries of some top government functionaries over the electronic mass media, on problematic and abbortive borehole installations.

Considering all these the need was therefore identified for a systematic study of the functioning of boreholes for potable water supply, with a view to utilising information so obtained in seeking the highest availability of the systems.

## 1.2 AIM AND OBJECTIVES

The study aims to systematically investigate the operational performance of rural community water supply systems in selected parts of Northern Nigeria, so as to generate data as inputs for the optimum availability design of the systems. The objectives are to:

(i) Articulate borehole systems' definition and project criteria.

(ii) Study systems' evaluation procedures and availability models.

(iii) Identify the nature and causes of borehole failures.

(iv) Evaluate the probability of survival and maintainability of handpump-equipped boreholes in the areas studied

(v) Identify the maintenance and repair requirements of the system.

(vi) Develop criteria for achieving the highest availability of the borehole system.

## 1.3 METHODOLOGY.

The objectives of this work are pursued through field investigations which concentrate on the collection of data on the operational reliability and maintainability of the systems. This entails evaluation of a number of boreholes in actual performance. The evaluation is effected by means of questionnaires designed to extract information from borehole project performance records; as well as by personal observation of some selected systems in actual performance. A random sample of 100 borehole records (over the initial five years) is drawn

from four states (Kaduna, Kano, Niger and Kwara) within the Crystalline Groundwater Province; and subjected to some statistical analysis. The major parameters of interest are:

i) Components and system failure frequency

ii) Probability of survival $P_s$ and probability of one or more failures $P_f$ in time T.

iii) Maintenance time constraint t, Maintainability M and Maintainability increment M .

iv) System Up-Time ratio UTR and Down-Time ratio DTR

v) Time to first failure of the system

The analytical tools employed include:

i) Simple statistical tabulation and pictorial presentation of data.

ii) Statistical interval estimation of relevant parameters (UTR and time to first failure) at 95% confidence interval.

iii) Analysis of Variance (ANOVA).

iv) Mathematical graphs.

Inference based on the utilisation of these tools as well as on qualitative assessment of the data by means of deductive reasoning are used to develop the criteria for improved availability of the handpump-equipped boreholes.

## 1.4 SCOPE AND LIMITATIONS OF THE STUDY.

The study focuses only on handpump-equipped boreholes which have been more widely used in the area of interest of this study and which have attracted the bulk of the investment in the

country's recent rural water supply schemes. Also whereas Nigeria has eleven groundwater provinces, each with its own characteristic hydrological features, the study concentrates on the crystalline groundwater province which accounts for about 50% of the country's landmass.

CHAPTER TWO

# RURAL WATER SUPPLY BOREHOLE SYSTEM DEFINITION AND THE ENVIRONMENT OF THEIR OPERATION.

## 2.0 Systems Concept.

An engineering system could be looked at as any device consisting of a number of components and parts; specially integrated to perform some specific operational function or functions -Rau (1970 p. 5). For the evaluation of a system therefore, an understanding of its components and parts, operating conditions and maintenance requirements; is often essential.

This chapter studies the components and parts of the handpump-equipped borehole system for rural water supply; the general socio-economic conditions in rural communities, and the hydro-geological features of the area of interest of this work (the crystalline groundwater province of northern Nigerian).

## 2.1 BOREHOLES

Barry (1978 p.2) described borehole as "a steel-lined shaft driven or drilled into the ground to a water bearing stratum". In Waterhouse (1982 p.118) boreholes were described as"tubewells" that is to say, wells of relatively small diameters lined usually with steel tubes. A more technical description of boreholes as lined-wells with depths in the range of about 10 to over 100 meters; and relatively small diameters in the range of about 30 to 600 millimetres could be derived from Okun and Earnest (1987 p.69). Here the borehole is seen to have four basic parts : casing, intake area, well head and water lifting device.

Figure 2.1 is an illustration of these four basic parts. It could however be seen from de Rooy et-al (1986 p.2) that a borehole system may in addition to the four basic parts include three other parts: storage tanks, distribution net-work of pipes and water treatment package.

2.1.1 Types of Boreholes

Okun and Earnest (1987 p.69) classified boreholes according to their methods of construction as : driven, jetted, bored, and drilled boreholes. They also highlighted that construction method selection depends on the depth of the aquifer, soil type, construction equipment and available financial resources.

Another classification of boreholes as: mechanised or handpump-equipped; on the basis of their equipment for operation, is found in de Rooy et-al (1986 p.2). This second classification is considered more relevant to this work and so will receive further attention.

a) Mechanised Boreholes.

Usually a mechanised borehole serves a population of about 5,000 people, and there are over 1,500 of them in Nigeria today - World Bank and Federal Republic of Nigeria (1986 p. 48). The major components of the system include:

(i) 60 to 250M deep borehole of 200 to 250mm diameter;

(ii) Water lifting device -usually a submersible pump together with starters cables and other necessary accessories;

(iii) power generating plant or National Electric Power Authority (NEPA) transformer;

(iv) elevated and sometimes ground-level water tanks;

(v) stand pipes or sometimes a distribution network of different diameters;

(vi) in certain instances a water treatment package.

Fig. 2.2 illustrates the components of a typical mechanised borehole.

b) Handpump-Equipped Boreholes.

Handpump-equipped boreholes have relatively shallow depths of less than 60M and each system ideally serves a population of 150 to 250 people - World Bank and Federal Republic of Nigeria (1986 p. 48). There are over 7,000 of these boreholes in Nigeria today. The major components of handpump-equipped borehole are:

(i) small diameter (100mm when cased) shallow borehole;

(ii) manually operated lifting device - handpump;

(iii) borehole platform (well head) made of concrete.

Plates 2.1 and 2.2 are examples of the above-ground features of a handpump-equipped borehole.

### 2.1.2 Design and Construction of Boreholes

Okun and Earnest (1987 p. 75-76) summarised the phases in the design and construction of boreholes as follows :

(i) Determination of required capacity

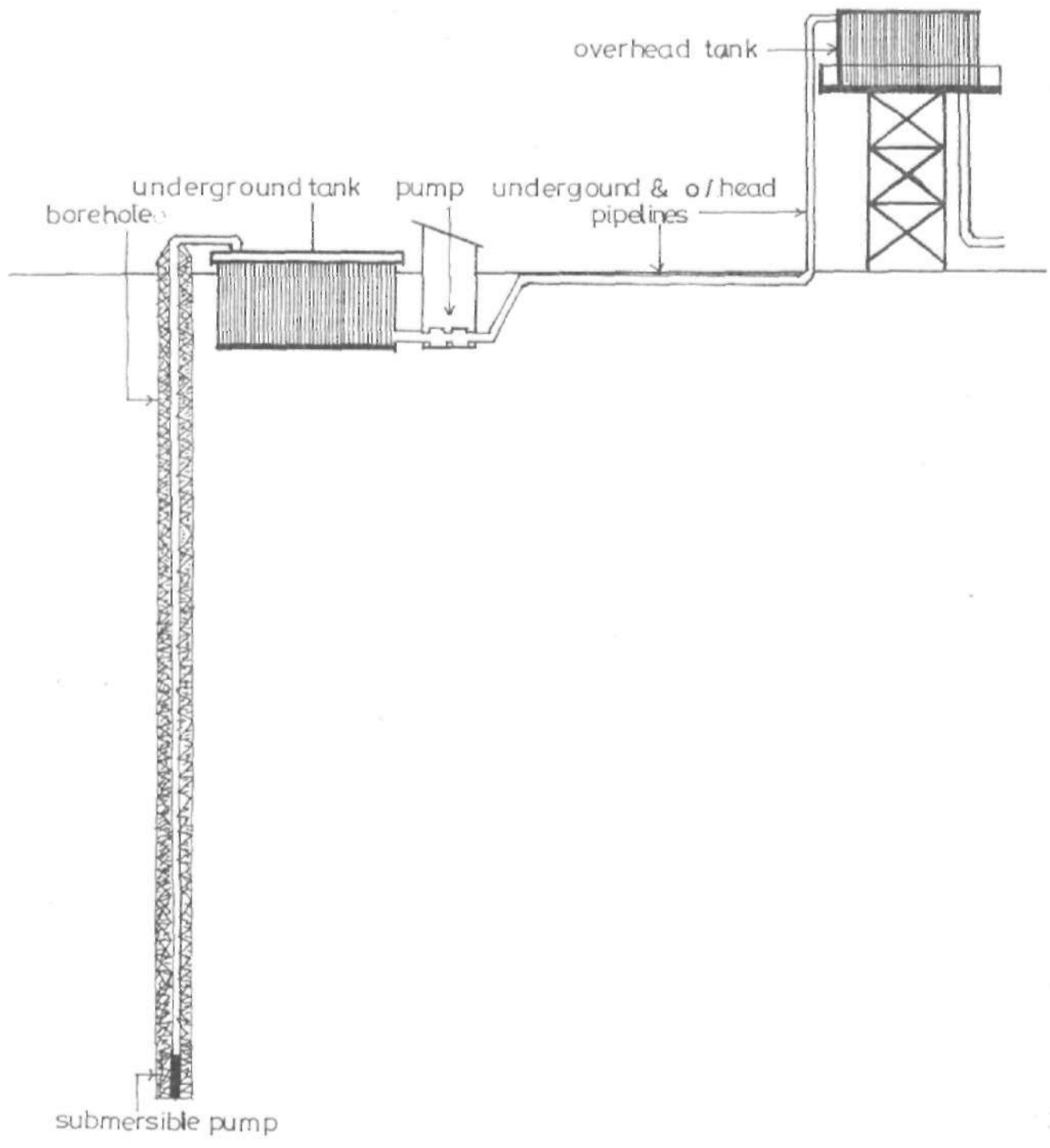



FIG. 2·2 Typical Mechanised Borehole



Plate 1 Handpump - Equipped Borehole

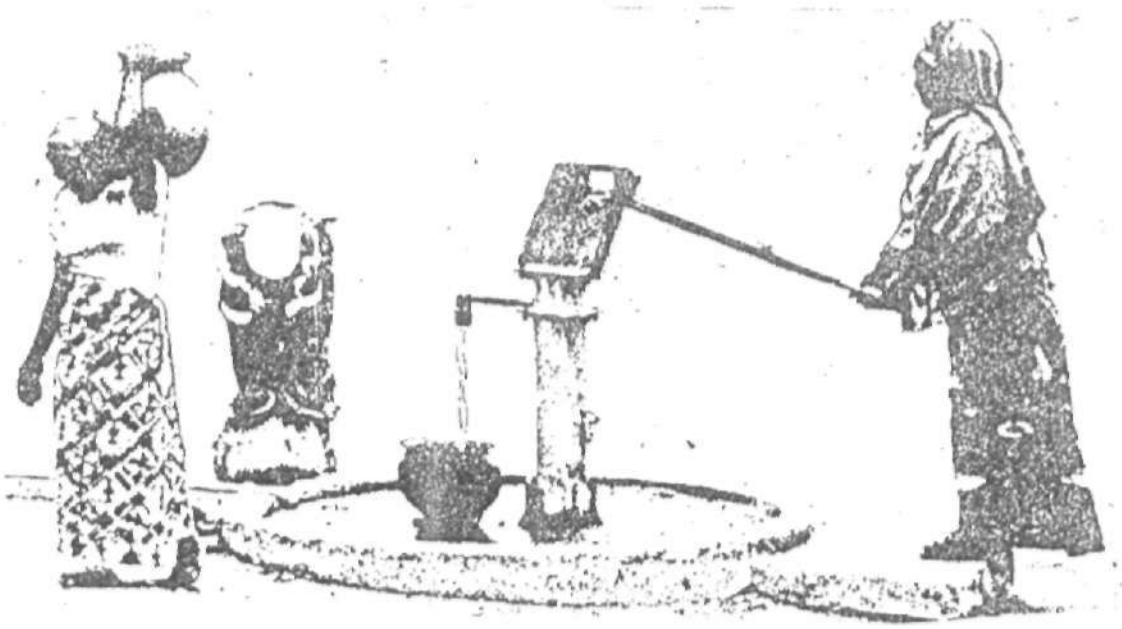


Plate 2 Handpump - Equipped Borehole

(ii) Hydrogeological information and investigation for source and site selection.

(iii) Selection of construction method and provisional design based on available data from nearby boreholes or small diameter test wells.

(iv) Sinking the borehole including careful sampling and recording of ground conditions. Soil samples are taken from each encountered layer and stored for possible sieve analysis.

(v) Final Design : final lay-out of well (casing, screen, filter) based drilling log and sieve analysis.

(vi) Borehole Alignment : control of verticality or plumbness and straightness for the proper installation of the casing and screen especially for boreholes with pumps below water and drives above ground. This is because deviations from the vertical affect the operation and life of the pump.

(vii) Installation of casings, screens, pumps and motors as well as the water quality protective devices.

viii) Well development so as to optimize the yield and life of the borehole. This enables its permeability to be increased by removal of the fine materials around the screen.

2.1.3 Yield of Boreholes

It has been established that for quantitative assessment of the yield of a borehole, the characteristics of the underlying aquifer namely : permeability and storativity

(or storage coefficient) must be known -Sahni (1981 p.151); Okun and Earnest (1987 p.65).

These aquifer characteristics can be established by analysing pumping test data from one or more observation wells not far from a pumped well. Several standard methods for this analysis based essentially on their non-equilibrium theory have been described in texts (Todd 1959; Walton 1970; Huisman 1972; Mcwhorten and Sunada 1977). More sophisticated analytical methods have also been reported in literature (such as Hantush and Jacob 1955;Boulton and Pontin 1971; Streltsova 1972).

Although these analytical methods are known to give useful detailed information about the aquifer they are found to be practically unsuitable in developing countries where ground water development often precedes any detailed assessment of the yield potential. Soliman (1972 pp74-79), and Sahni and Seth (1979 pp.205-212) have described methods for determining storage coefficient of an aquifer using ground water piezometer contour maps. Here observation wells are not necessary for monitoring aquifer performance in response to pumping in the main wells. The ground water maps are prepared using the static hydraulic head measurements in a few existing or abandoned wells in and / or around the new project area. Lazanyi et-al (1985 pp.39-49) reported the use of this method for the preparation of ground water contour map for Kano State.

In Okun and Earnest (1987 p.65) the formula for estimating the yield of a borehole was given as follows :

$$Q = C\frac{K(H^2-h^2)}{Log(\frac{R}{r})} \quad ....eqn.\ 2.1$$

where Q = the yield of the borehole

C = a dimensional constant

K = Permeability (mm/sec)

H = level of original water table

h = final level in the borehole

(H - h) = drawdown of the borehole

(2R) = Radius of influence of the borehole

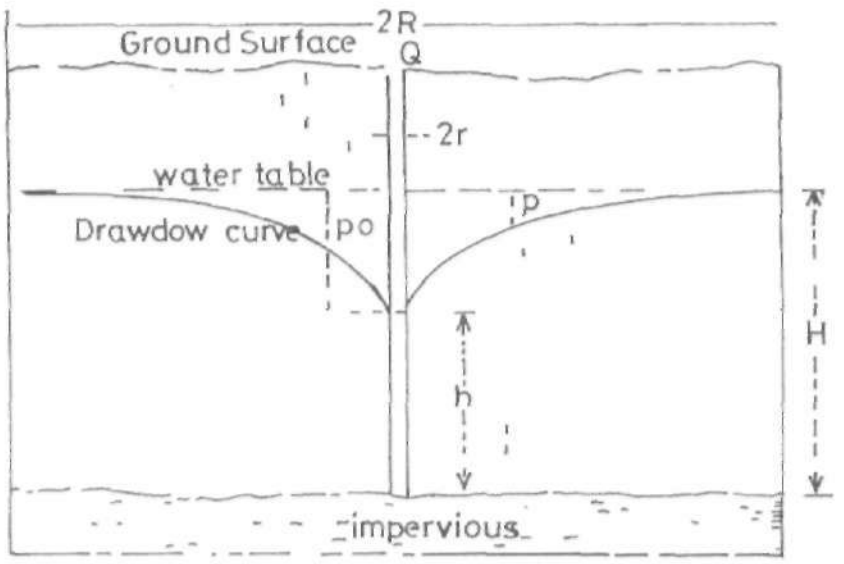
(2r) = diameter of the borehole

Figure 2.3 is an illustration of these parameters.

This relationship works on the assumption that the borehole withdraws water from an aquifer with an approximately horizontal water table and a steady flow to the borehole in all directions.

Two or a group of boreholes drawing simultaneously from an aquifer may increase the drawdown of each borehole if they are placed close together. The drawdown at any point in the area is approximately equal to the sum of the drawdowns caused by each well individually. Because the drawdown has a major impact on the yield, the distance between the boreholes must be adequate to avoid interference. The use of two boreholes is desirable so that one would serve as standby.

Assessment of the yield of boreholes is of importance to this work as it is a basic factor in the availability for use of the entire system.




po = Drawdown

FIG 2·3 BOREHOLE AND WATER TABLE IN A GROUNDWATER RESERVOIR

Source: Okun and Ernest (1987, P.66)

### 2.1.4 Borehole Water Quality

Hofkes (Ed.) 1981 p.130) as well as Okun and Earnest (1987 p. 77) highlighted certain precautions which are necessary for well water quality protection. First on the list is that the well top should be provided with a water-tight cover and the casing must be sealed off with cement grout and a concrete slab which slopes away from the well as shown in fig. 2.4. Next, the borehole is required to be disinfected with chlorine before it is put into operation and also after any maintenance work.

Regular maintenance is also necessary for wells so as to prevent a decline in their yield as well as eliminate chances of their complete loss. Sand and silt (which reduce the performance and lifetime of pumps and pipes) must be kept out of wells through programmed inspection and cleaning of the screens and patching of cracks in concrete casings.

## 2.2 PUMPS

Any device employed for vertical or horizontal transportation of water from one point to another can be called water lifting device or water pump. It has therefore been said that our first ancestor who cupped his hands and fetched water from a stream, chose the lifting technique appropriate to him. Today there is a wide variety of water pumps ranging from simple manually operated ones to diesel engines and electric motor pumps.

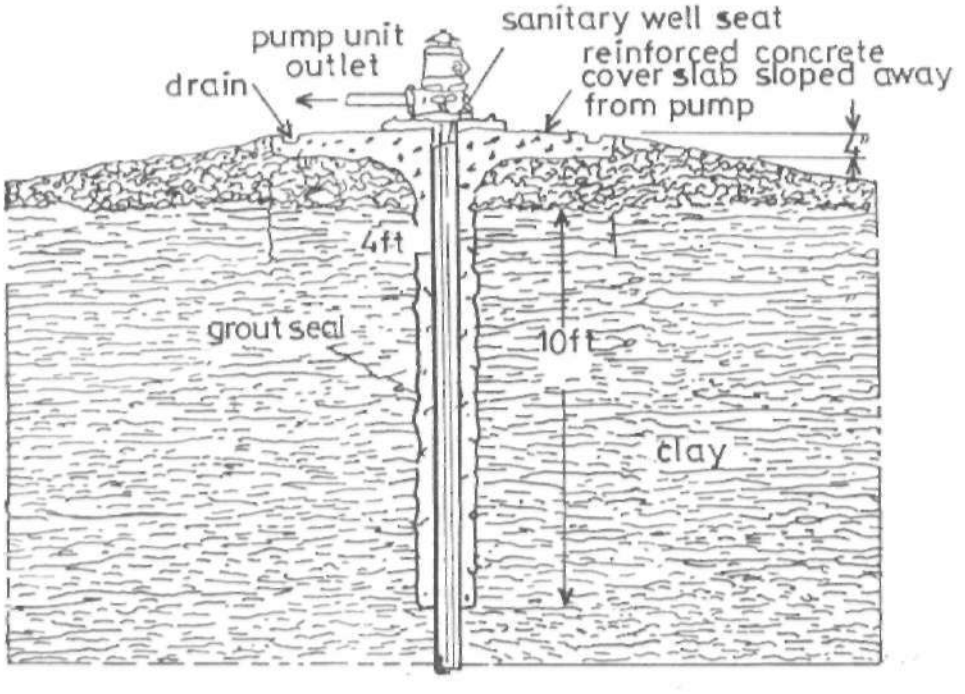



FIG 2·4 SANITARY PROTECTION OF UPPER TERMINAL OF BOREHOLE

Source : USAID (1969 ), in Okun and Ernest (1987, P.78 )

Water pumps are classified either by their power source or by their mechanical principle of operation - Hofkes (Ed) (1981 pp. 163-167) and Frankel (Ed) (1986 pp. 208-222). By power source we have: (a) human powered pumps; (b) animal powered pumps; (c) wind powered pumps; (d) electric motor pumps; (e) diesel engine pumps; (f) solar powered pumps. By their mechanical principle of operation, pumps may be classified as : (a) reciprocating; (b) Rotary (positive displacement); (c) axial flow (propeller); (d) centrifugal; (e) airlift.

This second classification of pumps is more relevant to this work and is therefore given further consideration.

**(a)** Reciprocating Pump.

This has a plunger (or piston) which moves up and down (reciprocates) in closed cylinder for positive displacement of water. It is most frequently used for small water supplies and its various types may be distinguished as:

**(i)** Suction or Lift pumps : depending on the arrangement of the plunger and its cylinder, and the utilisation or non- utilisation of the atmospheric pressure in the pumping work. Since the suction pump utilises atmospheric pressure, its utilisation is restricted to well water levels not exceeding 7 meters. Its plunger and cylinder are located above the water level, usually within the pump stand itself. In the lift pump the plunger and the cylinder are located below the water level in the well. It does not depend on atmospheric pressure and can therefore lift water from wells as deep as 180 meters.

Figures 2.5 and 2.6 are illustrations of the suction and lift pumps respectively.

(ii) Free Delivery or Force Pumps : depending on levels to which water is to be delivered. The force pump is designed to pump water from a source and deliver it to a higher elevation or against pressure. The features of the force pump are illustrated in figure 2.7.

(iii) Single-Acting or Double-Acting : depending on whether the piston discharges water at only one or both strokes of the piston. The single-acting pump discharges water at only the up stroke while the double-acting pump discharges water at both strokes and is therefore significantly more productive for its size than the single-acting one - Fraenkel (Ed.) (1986 pp 50).

(b) Rotary Pumps

Examples of the rotary (positive displacement) pump are chain pumps and helical rotor pumps the essential features of which are shown in figures 2.8A and 2.8B. The rotation of the moving part (endless chain with rubber disc for the chain pump; steel rotor for the helical rotor pump) over or in the stationary part (wheel with teeth for the chain pump; steel rubber stator for the helical pump) creates the power that lifts water up to the spout.

Helical rotor pumps are known to have performed well for deep wells in parts of Africa and Asia - Hofkes (Ed) (1981 p 177).

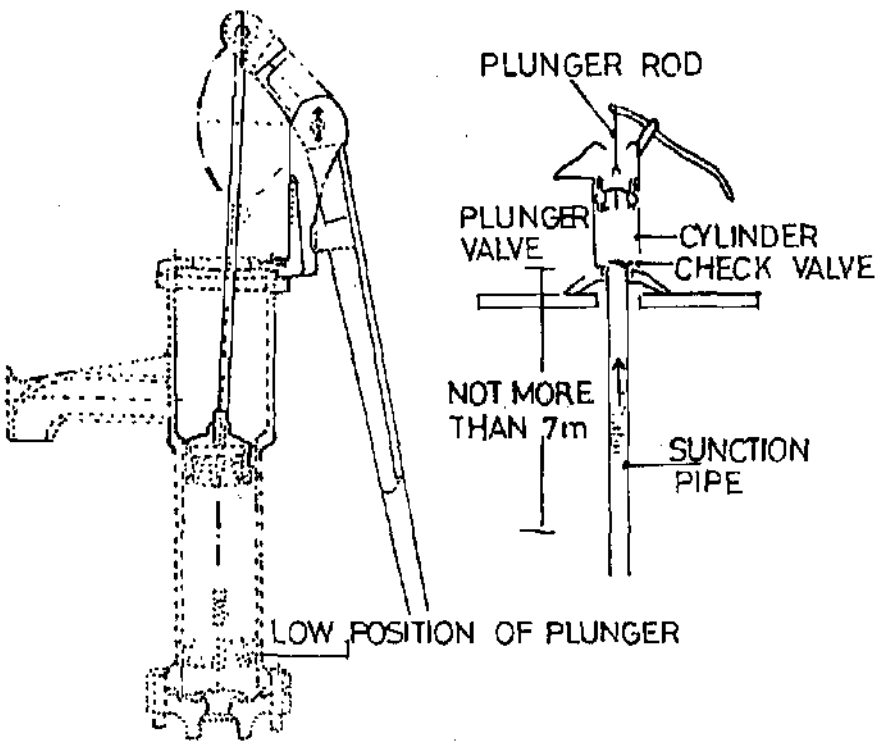



FIG. 2·5 SUCTION PUMP (SHALLOW WELL)

Source: Hofkes (1981 P.170)

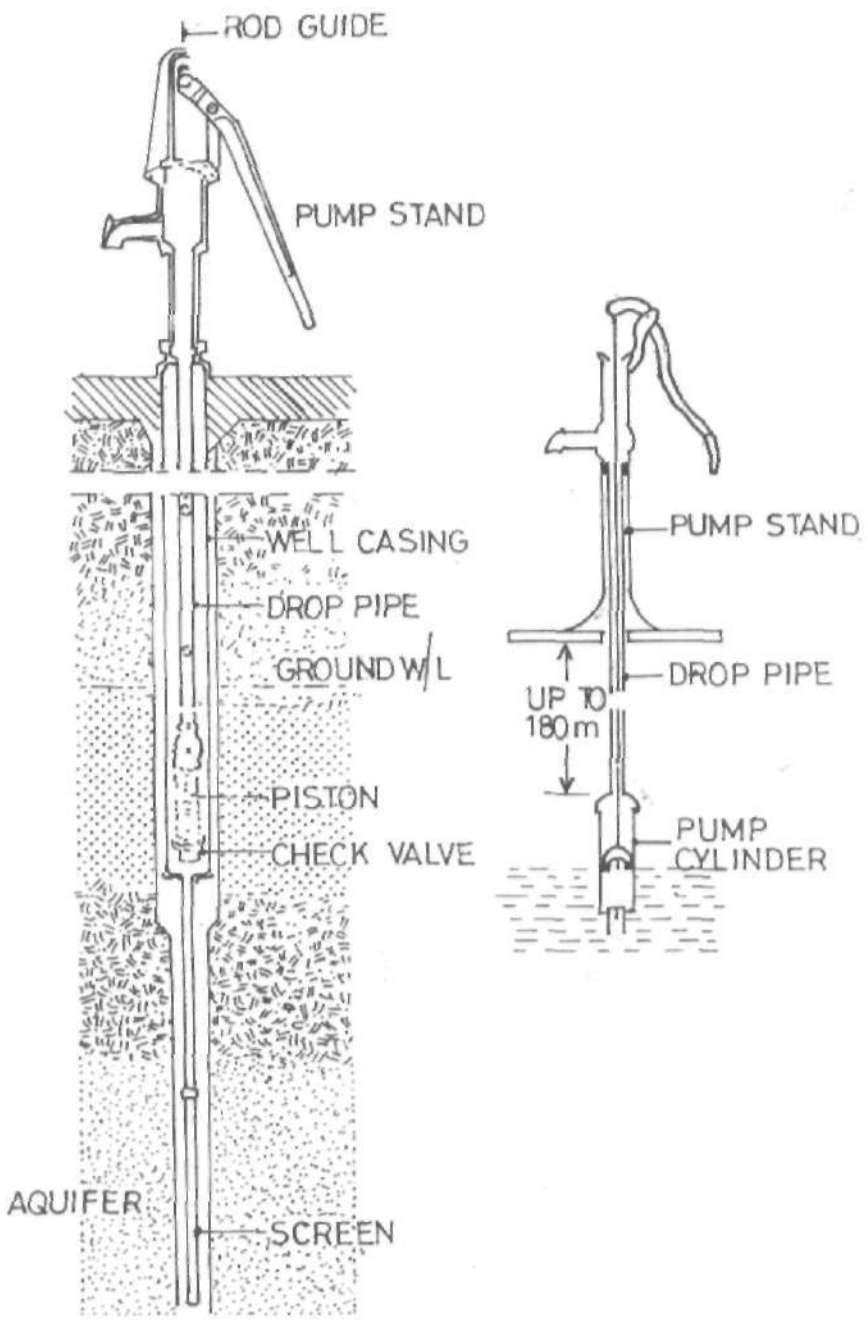
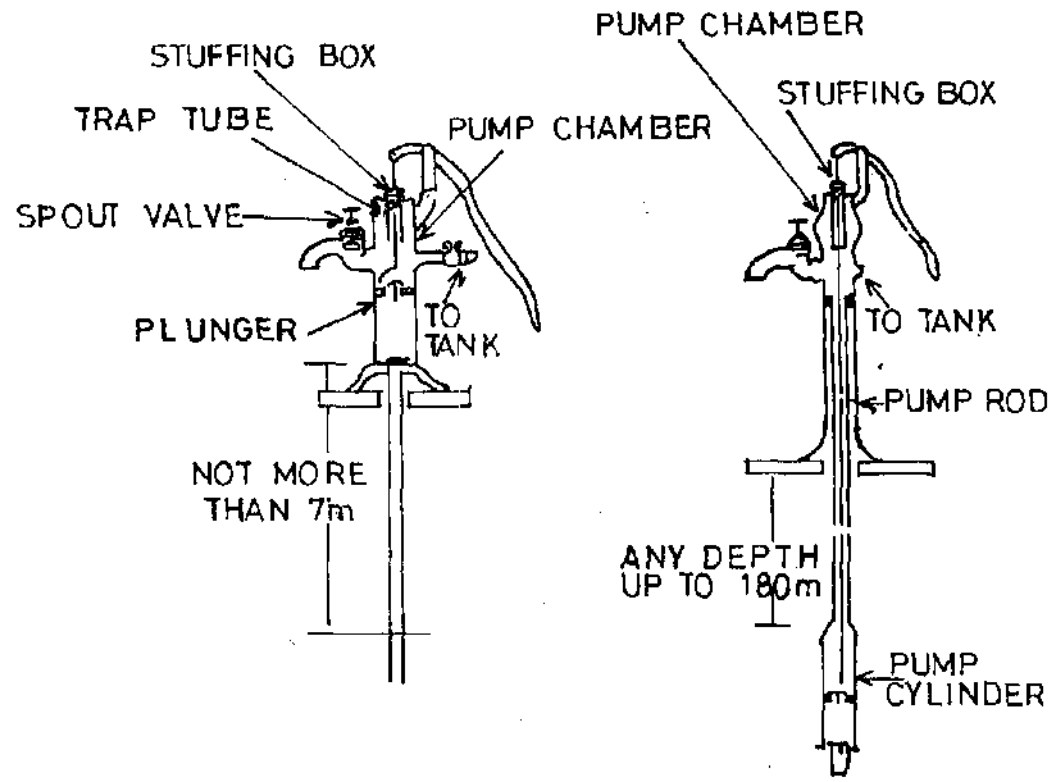



FIG. 2·6 LIFT PUMP (DEEP WELL)

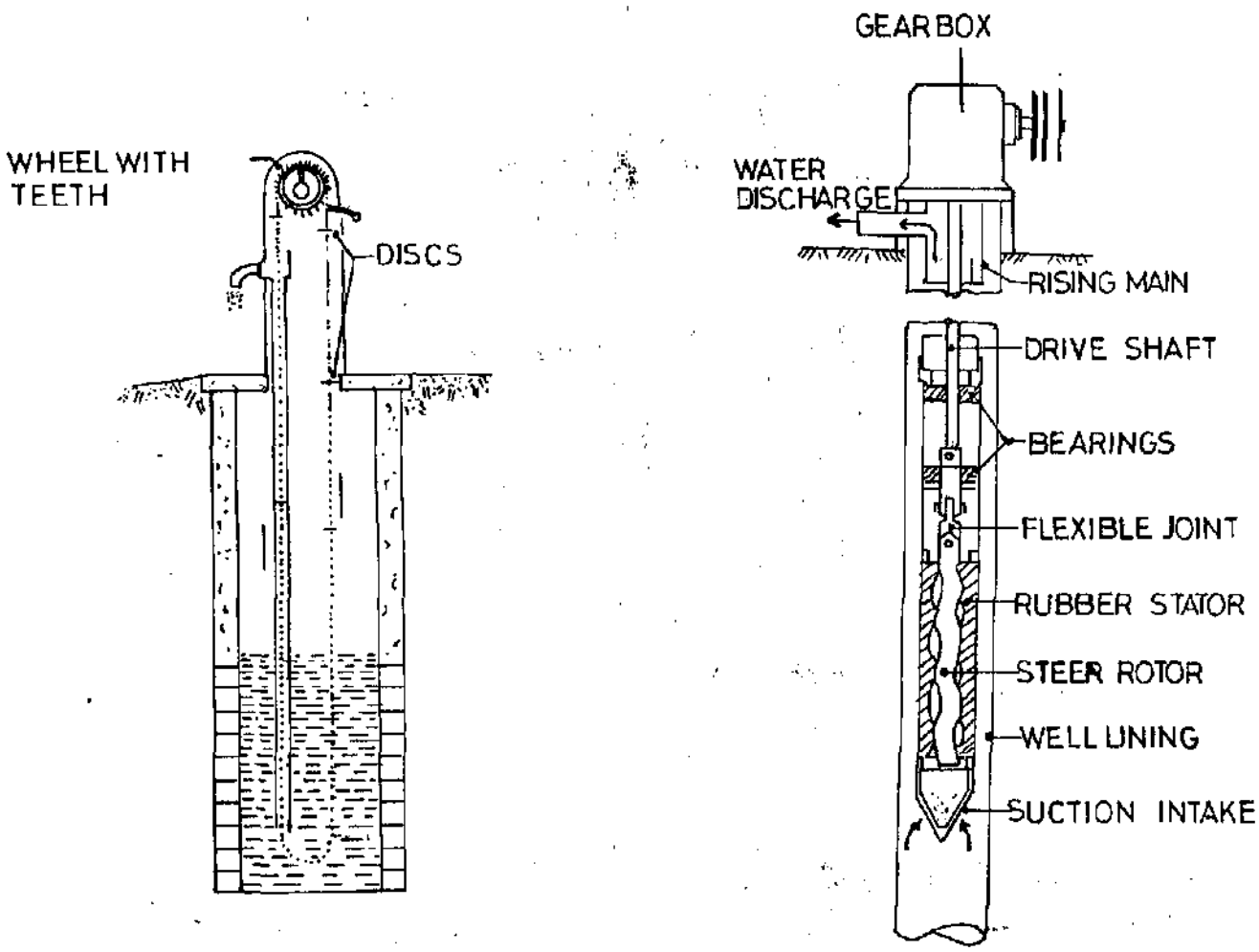
Source: Hofkes (1981, P172)




A) FORCE PUMP ON SHALLOW WELL  B) FORCE PUMP ON DEEP WELL

FIG 2·7 FORCE PUMPS

Source: Hofkes (1981, P.173)




A. CHAIN PUMP

B. HELICAL ROTOR PUMP

FIG. 2.8 ROTARY PUMPS

Source Hofker (1981, PP. 175 & 176 )

c Axial-Flow Pumps

These pumps mechanically lift water by the action of a rotating impeller or wheel on which are mounted radial fins or blades which ensure that the water has no "whirl" velocity as it enters or leave the impeller (see fig.2.9) The impeller and the blades are in a stationary enclosure called the casing.

d Centrifugal Pumps

The centrifugal pump is designed with a casing so shaped that the rotation of an impeller (a wheel having vanes radiating from the centre to the periphery) imparts kinetic energy to the water which, as it leaves the impeller has part of this kinetic energy converted into useful pressure for lifting the water.

An impeller and the matching section of the casing is called a stage. For high pumping heads, a number of stages may be placed in series (multiple-stage pump) , the impellers being attached to a common shaft so as to rotate at the same speed (see fig. 2.10).

Efficiency of centrifugal pumps tends to increase as the speed increases but higher speed often leads to more frequent maintenance. A balance is to be therefore aimed at between the initial cost and maintenance cost.

e Air Lift Pumps

An air-lift pump injects small evenly distributed bubble of compressed air at the foot of a discharge pipe fixed in the well. The air-water mixture being lighter than the

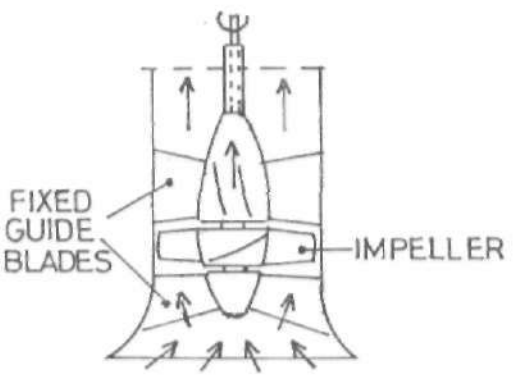



FIG 2·9 AXIAL FLOW PUMP

Source Hofkes (1981, P.177)

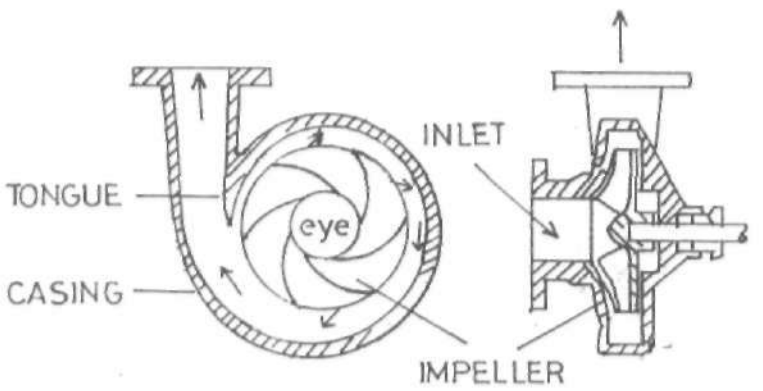



FIG 2·10 CENTRIFUGAL PUMP WITH VOLUTE—TYPE CASING

Source Hofkes (1981, P.178)

water outside the discharge pipe, is forced upward by the hydrostatic head. A compressor is necessary for the operation of an air-lift pump. The pumping head (h) against which an air-lift pump can raise water, is related to the submergence (S) of the discharge pipe (see figure 2.11).

Low mechanical efficiency about 25-40% in utilising the energy supplied to it for lifting of water is a major drawback of the air-lift pump. It is however simple to operate and is not affected by sand or silt in the pumped water.

Table 2.1 gives a concise technical information on the characteristics and applicability of the various types of pumps.

### 2.2.1 Handpumps - Types and Components

There are quite a good number of handpumps in the market today; some locally manufactured and others imported. The handpump most widely in use in Nigeria however is the India Mark II, and to lesser extent its modified version - India Mark III. Figures 2.12 and 2.13 are illustrations of the components of the India Mark II handpump while figures 2.14 and 2.15 show same for the India Mark III.

The major components of both pumps can be summarised as follows:

1) Head Assembly
2) Water Tank Assembly
3) Stand Assembly
4) Casing

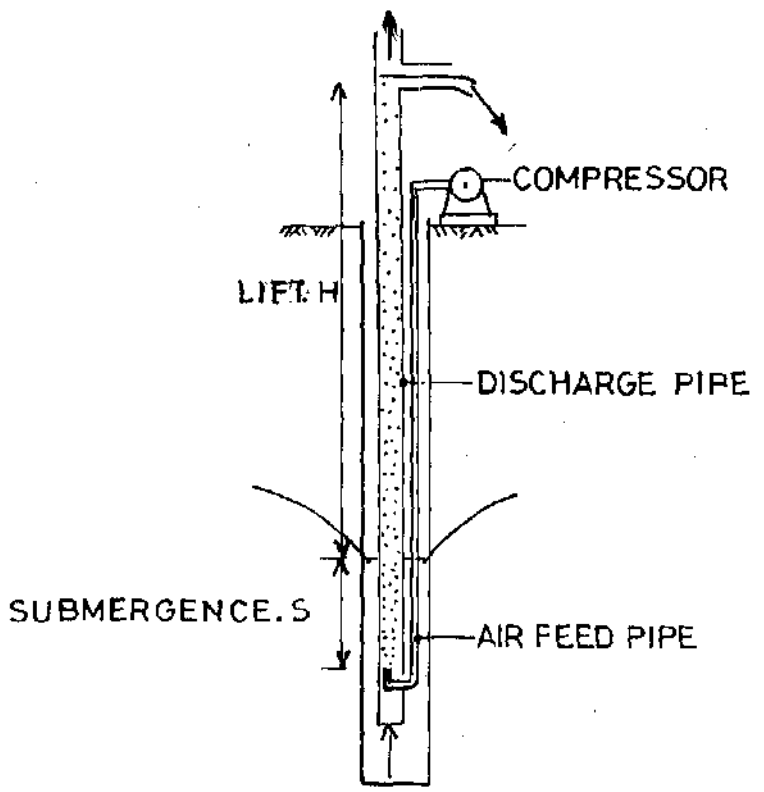



FIG 2.11 AIR-LIFT PUMP (SCHEMATIC)

Source: Hofkes (1981, P.183)

TABLE 2.1 - INFORMATION ON TYPES OF PUMPS

| TYPE OF PUMP | USUAL DEPTH RANGE | CHARACTERISTICS AND APPLICABILITY |
|---|---|---|
| RECIPROCATING (plunger) | | Low speed of operation; hand, wind or motor-powered; Efficiency low. |
| a. Suction (shallow well) | Up to 7m | Capacity range: 10-50 litres/min suitable to pump against variable heads; valve and cup seals require maintenance attention. |
| b. Lift (deep well) | Up to 7m | |
| ROTARY (positive displacement) | | Low speed of operation; hand, animal, wind powered; |
| a. Chain and bucket pump | Up to 10m | Capacity range 5-30 litres/min discharge constant under variable heads. |
| b. Helical rotor | 25-150m Usually submerged | Using gearing; hand, wind or motor powered; good efficiency, best suited to low capacity-high lift pumping. |
| AXIL-FLOW | 5-10m | High capacity - low lift pumping; can pump water containing sand or silt. |
| CENTRIFUGAL | | High speed of operation - smooth even discharge; efficiency range 50-85% depending on operating speed and pumping head. |
| a. Single-stage | 20-35m | Requires skilled maintenance; not suitable for hand operation; powered by engine or electric motor. |
| b. Multi-stage (shaft-driven | 25-50m | As for single-stage. Motor accessible, above ground, alignment & lubrication of shaft critical: Capacity range 25-10,000 L/min |
| Multi-stage (submersible) | 30-120m | As for multi-stage shaft-driven; Smoother operation; maintenance difficult ; repair to motor or pump requires pulling unit from well : wide range of capacities and heads; subject to rapid wear when sandy water is pumped. |
| AIR-LIFT | 15-50m | High capacity at low lift; very low efficiency at greater lifts; no moving parts in the well; well casing straightness not critical. |

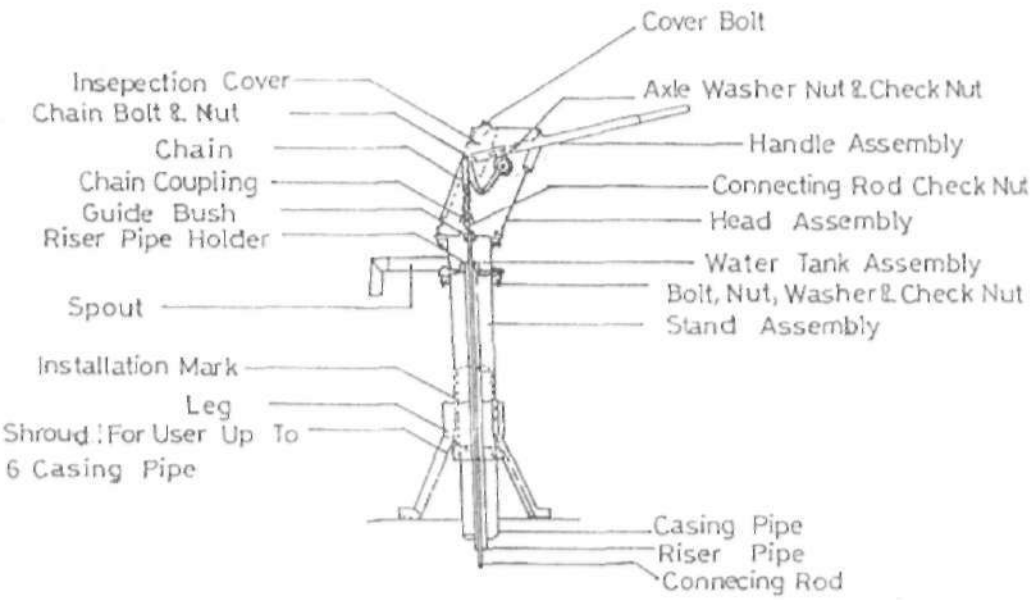



FIG. 2-12 Sectiona Details of Above Ground Components of India Mark II Pump

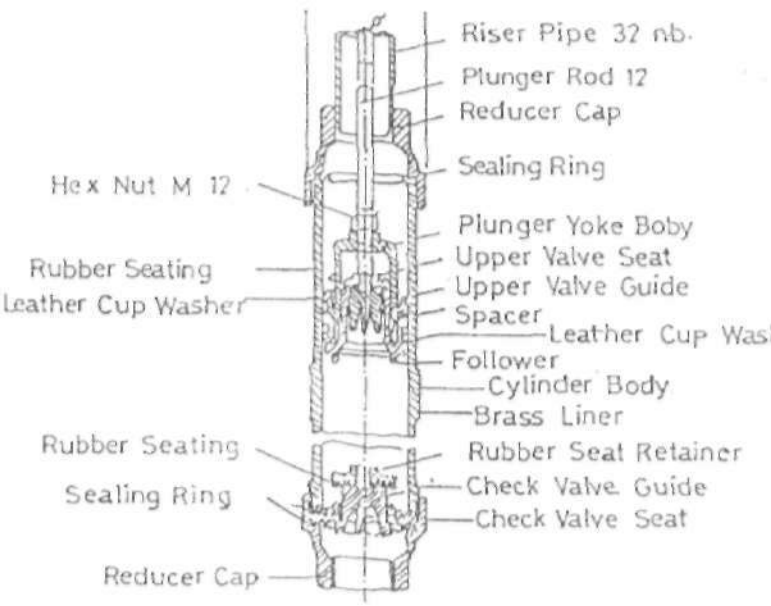



FIG. 2-13 Cylinder Assembly of India Mark II Handpump

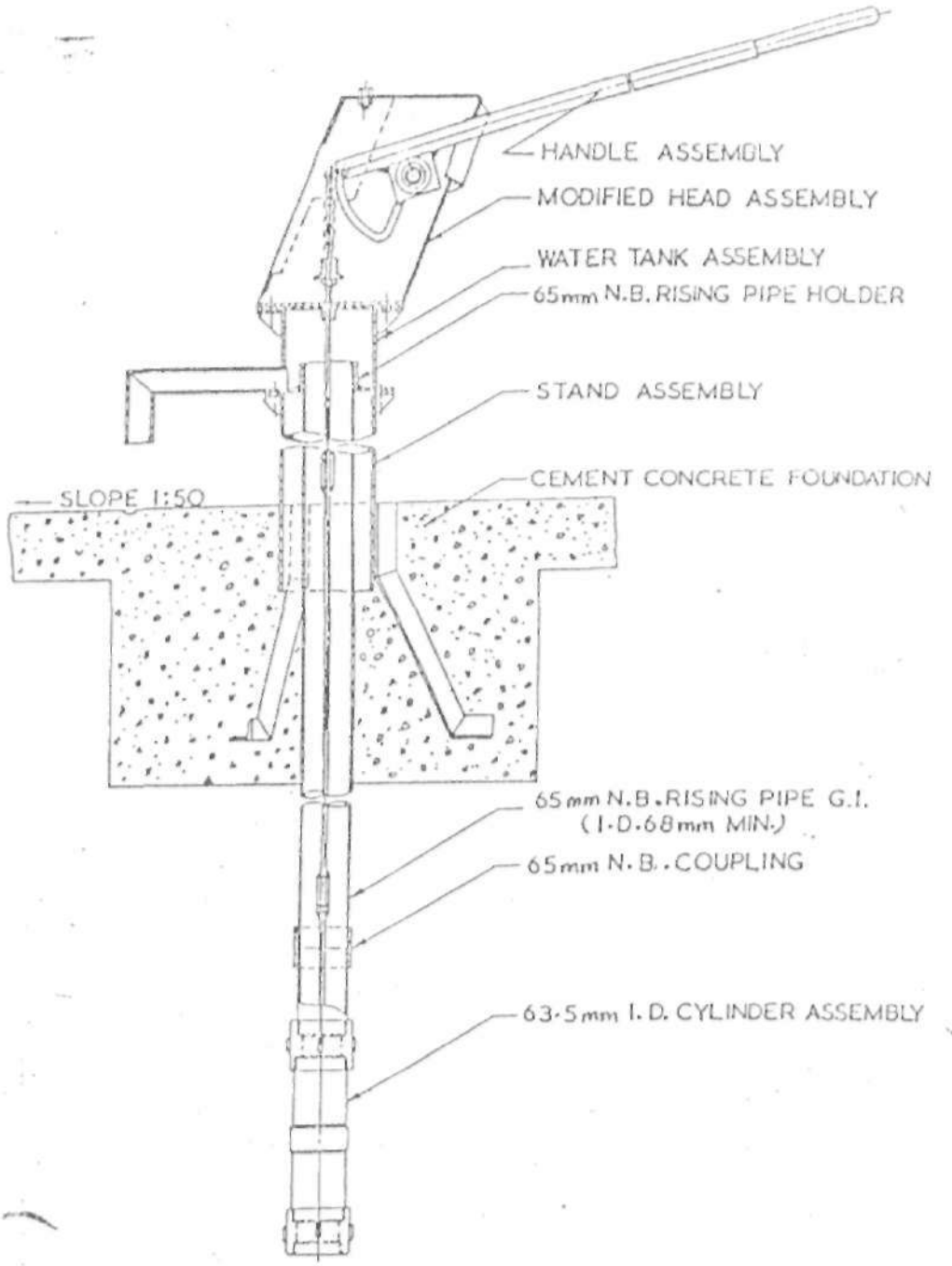



FIG. 2.14 Sectional Details of Above Ground Components of India Mark III Handpump

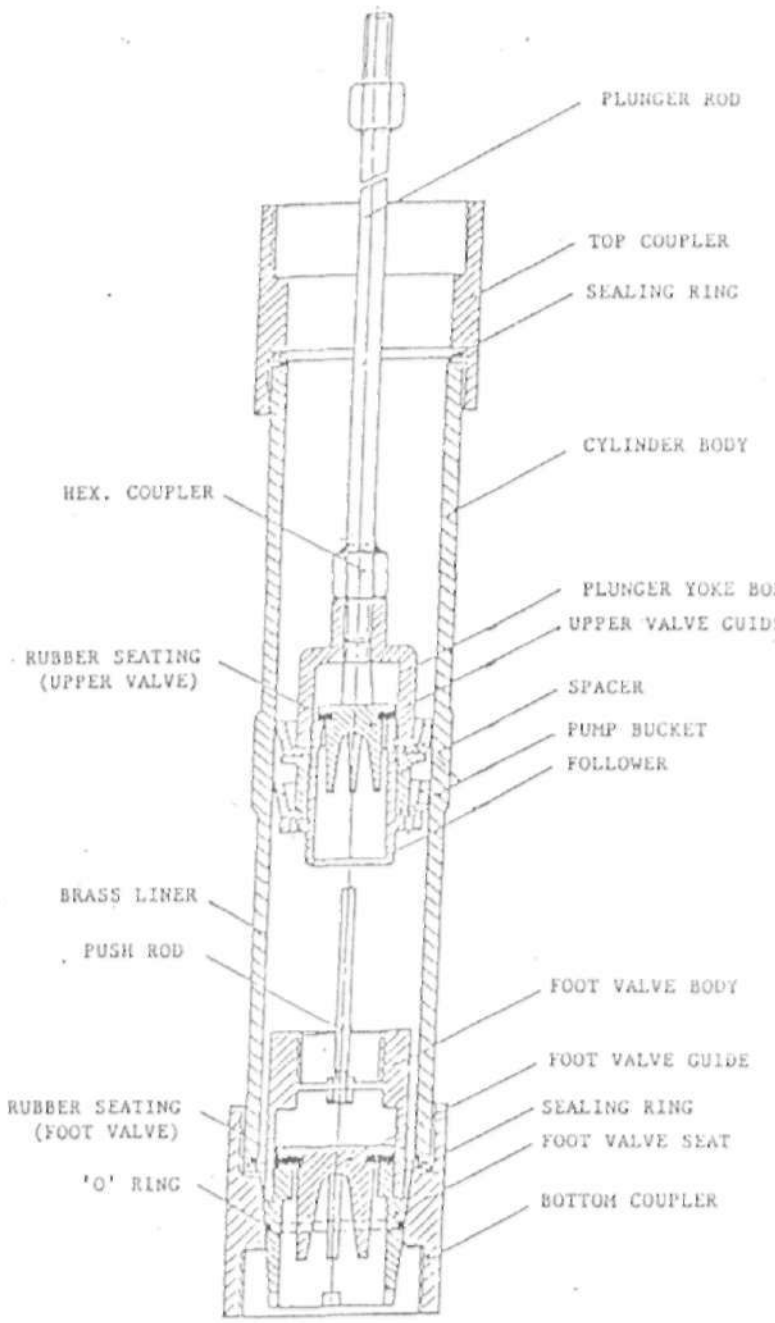



FIG. 2.15 Cylinder Assembly of India Mark III Handpump

5) Riser Pipe

6) Connecting Rod

7) Cylinder Assembly.

table 2.2 shows the performance indices of types of India Mark II handpumps.

Table 2.2 Performance Indices of Types of India Mark II Handpumps - Donaldson and Karim (1988 p. A4).

| Item | Particulars | Unit | Standard | Extra Deep | Open Top |
|---|---|---|---|---|---|
| 01 | Installation depth - Maximum | Metre | 60 | 90 | |
| 02 | Installation depth - Optimum | Metre | 28-33 | 40-75 | |
| 03 | Cylinder internal diameter | mm | 63.5 | 63.5 | 63.5 |
| 04 | Stroke length | mm | 100 | 100 | 100 |
| 05 | Strokes per minute (average) | No. | 40-50 | 40-50 | 40-50 |
| 06 | Discharge per stroke | Litre | 0.32 | 0.32 | 0.32 |
| 07 | Discharge per 15 strokes | Litre | 4.8-5.5 | 4.8-5.5 | 5.0-5.5 |
| 08 | Discharge per minute | Litre | 12-15 | 12-15 | 12-15 |
| 09 | Discharge per hour | | 800-1000 | Same | Same |

2.2.2 Pump Reliability and Maintenance

Pump failures are known to be major causes of breakdowns in the functioning of boreholes in the rural communities. Pump reliability and maintenance are therefore strong factors in the availability of the overall system.

In assessing the reliability of a pump, Alosorof et-al (1987 pp 75) observed that the important factor is not just the length of time before failure, but also the time taken by the maintenance organisation to respond to the breakdown and effect repairs. They further observed that most pump failures result

from wear and that the breakdown frequency is related to the intensity of pump use.

### 2.2.3 Pump Selection Criteria

Fraenkel (Ed) (1986 pp 267-289), presented criteria and procedures for assessing the cost effectiveness of water pumps. The "life-cycle costs" are compared with life-cycle benefits and a suitable format which allows ready comparison amongst the options could then be adopted.

Arlosorof et-al (1987 pp 70-101) presented a more comprehensive list of selection criteria for hand pumps, a summary of which is given in table 2.3. The major features considered are as follows :

(a) Operating conditions : range of pumping lifts, the amount of water to be pumped each day, the corrosivity of the water and the potential for sand pumping.
(b) Maintenance system to be employed.
(c) Potential for local manufacture.

These criteria when supported with up-to-date cost-benefit information will ensure a thorough selection of the pumps to match specific project conditions.

## 2.3 BOREHOLE FAILURES

For a handpump-equipped borehole, failure may be defined as a deterioration or loss in performance or operating characteristics of the well or pump or both - Driscoll (1989 p.630).

Table 2.3 Selection Criteria of Handpump for Rural Water Supply

NAME OF PROJECT

MAXIMUM PUMPING LIFT — Meters

Selection Table for this lift

DAILY OUTPUT PER PUMP — $M^3$ / day

MAINTENANCE SYSTEM TO BE USED (A, B or C)

Where A = Village-level maintenance
B = Area-mechanic maintenance
C = Centralised maintenance

MAXIMUM RATING NEEDED FOR CORROSION RESISTANCE

Where - = Corrosion resistance not required
0 = Resistance to mildly corrosive water required
00 = Resistance to aggressive water is required

MINIMUM RATING NEEDED FOR ABRASION RESISTANCE

Where - = Either there is no sand pumping anticipated or there is a possibility of trace sand pumping and daily output will not be greater than 1.5m.
0 = There is a possibility of trace sand pumping and daily output will be greater than 1.5m.
00 = There is a possibility of significant sand pump.

MANUFACTURING ENVIRONMENT (1, 2 or 3)

Where 1 = The pump is to be made in the country, and there is low level of industrial base.
2 = The pump is to be made in the country, and there is medium-level of industrial base.
3 = The pump may be imported or made in a country where there is a high-level of industrial base.

PUMPS ALREADY PERFORMING SATISFACTORILY IN THE COUNTRY

(* IF ALSO MANUFACTURED IN THE COUNTRY)

### 2.3.1 Well Failure and Rehabilitation

Driscoll (1989, pp, 630-667) defined well rehabilitation as "restoring a well to its most efficient condition by various treatments or reconstruction methods". He listed four major problems which occur with wells over time as:

a. Reduction in well yield
b. Plugging of the formation around the well screen by fine particles
c. Onset of sand pumping
d. Pump condition

a). Reduction in the Well Yield

This may be caused by a number of factors such as:

i) Chemical incrustation or biofouling of the well screen and the formation of materials around the intake portion of the well. Thus far a means of preventing the incrustation of well screens has not been found but good design and construction methods (screens with maximum possible inlet area to reduce flow velocity through the screens, thoroughly developed wells and reduced pumping rates) can delay the rate of incrustation and make it a less serious problem. Chemical incrustation is best removed by treating the well with a strong acid (such as hydrochloric acid HCl, Sulfanic acid $H_2NO_3S$ and hydroxyacetic acid $C_2H_4O_3$) that chemically dissolves the incrusting materials so that they can be pumped from the well.

ii) Environmental factors. These include such occurrences as: general drop in water tables caused mainly by short- or long-term climatic trends, interference from nearby wells and

continuous pumping above the aquifer transmissivity.

iii) Plugging of the formation around the well screen by fine particles. Small particles in most unconsolidated formations or in wells constructed in igneous and metamorphic rocks, are disturbed during pumping, and while temporarily in suspension move towards the screen or accumulate in the rock cracks, fissures, joints, fractures or cavities that produce most of the water to the well.

**b.** Onset of Sand Pumping

In new wells, sandpumping is attributable to poor well design and development but corrosion and incrustation are major causes of sand pumping that develop over time. Treatment often involves well re-development and screen rehabilitation.

c. Structural Collapse of Well casing or Screen.

Stuctural collapse often results from low-PH (acidic) water containing high total dissolved solids and carbon dioxide concentrations that combine to cause electrolytic corrosion along the casing below the static water level. Rehabilitation in this case entails installation of new casing and screens.

**d.** Pump Condition

Mistakes in the design and construction of a well can cause severe damage to the pump over time. Sand Pumping and corrosion of pump parts by low-PH waters can drastically reduce the efficient life of the pump.

### 2.3.2 Handpump Failures And Maintenance

It has been mentioned earlier in section 2.2.2 that pump failures account for the greater portion of breakdowns in the functioning of boreholes for rural community water supply. Table 2.4 summarises the nature, causes and remedy of the major problems encountered, over time, with the use of the India Mark II handpumps. Below is a check list presented by Donaldson and Karim (1988, p. A14) as a guide to maintenance teams in their routine inspection and service of the India Mark II handpump.

**I. Routine Inspection - Once a Month**

i) Carry out flow test for corrective discharge from the pump.

ii) Open the inspection cover, clean inside the head.

iii) Clean the chain assembly and grease.

iv) Check the chain anchor bolt for proper fitment; tighten if necessary.

v) Tighten all loose bolts and nuts.

vi) Find out whether the pump base is loose in the foundation. If loose arrange for fresh foundation.

vii) Check bearing play on handle assembly.

viii) Record water quality - visual.

ix) Record complaints from handpump users.

x) Clean drainage and environs.

**II. Routine Service - Once a Year (10-12 Months)**

a. Examine the pump carefully and check whether:

Table 2.4: Nature, Causes and Remedy For Common India Mark II Handpump Problems

| Trouble | Cause | Remedy |
|---|---|---|
| (1) Pump handle works easily but no flow of water | (a) Riser main cracked | (a) Replace the Rising |
| | (b) Cylinder cracked | (b) Replace cylinder |
| | (c) Valve seals worn out | (c) Replace valve seals |
| | (d) Piston cups damaged | (d) Replace the cups |
| | (e) Connecting rod or piston disconnected. | (e) Pull out the pump and join the connecting rod or the piston where necessary. |
| | (f) Foot Valve assembly dismantled. | (f) Refit the components, tighten and dot punch. |
| | (g) Plunger valve Assembly dismantled | (g) Refix the components, tighten & dot punch. |
| | (h) Water level gone down below cylinder | (h) Extend the length of riser pipes. |
| (2) Small Water Flow | (a) Valve seals worn out | (a) Replace valve seals |
| | (b) Piston cups damaged | (b) Replace the cups |
| (3) Delayed Water flow (i.e. water flow starts after several strokes) | (a) Leakage of foot valve | (a) Check seals on foot valve replace them if worn out. Tighten the nut firmly. Clean the valve seat. |
| | (b) Leakage in rising pipe assembly. | (b) Refit all joints on riser pipe, or replace damaged. |
| (4) Folding of chain during return stroke. | (a) Piston cups getting jammed inside cylinder | (a) Overhaul the the cylinder and replace piston cups |
| | (b) Connecting Rod length incorrect | (b) Check and follow Manual. |
| (5) Unusual noise during operation | (a) Stand assembly flange not levelled properly | (a) Level the flange |
| | (b) Bent connecting rod | (b) Change the defective rod. |
| (6) Shaky Handle | (a) Loose handle axle nut. | (a) Tighten handle axle |
| | (b) Worn out ball bearing | (b) Replace ball bearing |
| | (c) Spacer damaged | (c) Replace spacer |
| | (d) Bearing Seat on Handle Assembly Worn. | (d) Replace Handle Assembly |
| (7) Handpump loose in its foundation. | Cracked foundation | Repair damaged area and allow cement to set for one week. |

i) Discharge is satisfactory (carry out flow test).

ii) Check bearing play on Handle assembly.

iii) Guide bush has excessively worn out.

iv) All bolts, nuts and washers are in position.

v) Chain has worn out.

vi) Roller chain guide is excessively worn out.

**b.** Pull out the pump and follow the instructions below.

i) If chain, bearing and spacer are damaged, replace worn out components accordingly.

ii) If roller chain guide is badly worn out, replace handle assembly.

iii) Dismantle pump cylinder - inspect and replace worn out metal parts. Replace all cup washers, sealing rings and rubber seating.

iv) Check all sub-assemblies for crack in weld and other visual defects. If defects are serious replace them.

v) Look for rust patches. If seen, clean them with a wire brush or sand paper and apply anti-corrosive paint.

vi) Clean all connecting rods and riser pipes with soap and water.

vii) Repair/replace damaged connecting rods and riser pipes.

viii) Check (measure) total depth of the borehole and the static water level.

ix) Reinstall the pump and perform flow tests.

## 2.4 RURAL BOREHOLE MAINTENANCE ORGANISATION SYSTEMS

Three types of maintenance organisation systems have been identified for rural community water supply. These are: Village-

Level Maintenance, Area-Mechanic Maintenance and centralized Maintenance - Alosorof et-al (1987 pp. 74 and 75).

a). Village Level Maintenance: All routine inspection, adjustment and replacement of worn-out parts, is carried out by a village repairer having minimal training and simple tools. Common spare parts are available to the village. External (expert) assistance may be required for catastrophic failures such as dropped riser pipe, connecting rod or cylinder, clogged screen and infilled well.

b). Area-Mechanic Maintenance: A locally based trained mechanic carries out the repair and maintenance with the assistance of the villagers. He is equipped with special tools and a bicycle or other simple transportation, and has access to special spare parts. He services several pumps in the area. Area mechanics may be under the responsibility of a water authority or other agency outside the village.

c). Centralized Maintenance: A team of trained technicians equipped, as a minimum, with special tools and workshop facilities, attends to breakdowns and sometimes undertakes scheduled maintenance.

Organisations a. and b. above are recommended as appropriate for conditions in most rural communities of developing countries. They are consistent for example with "Village Level Operation and Maintenance (VLOM) System" in use today in the country for the UNICEF

water and Sanitation (WATSAN) Projects - Donaldson and Karim (1988, pp. 1-15).

The higher cost of administration of organisation c. as well as the delay normally experienced before response to breakdowns, make it less attractive for developing countries.

## 2.5 SOCIO-ECONOMIC AND ENVIRONMENTAL FEATURES OF NIGERIA's RURAL COMMUNITIES

This section aims to briefly describe the social, economic and hydrogeological features of rural communities in this work's area of interest; as a means of facilitating understanding of the background conditions of operation of the borehole systems under evaluation.

### 2.5.1 Socio-Economic Characteristics

Over 70% of Nigeria's population are rural dwellers and mostly of agricultural-based village communities. A few scattered towns are however also known to exist. The set-up is usually small villages spread over a large expanse of land, with populations generally below 1,500. There are also a few villages with a population in the range of 2,500 to 4,000; as well as few rural towns with populations generally over 5,000 - UNICEF and Federal Ministry of Health (1986 pp. 1-23), de Rooy et-al (1986, pp. 1-9), Donaldson and Karim (1988, pp. 1-15).

Life in these villages is usually characterised by low levels of education, income and technical skills. Also supporting infrastructure are usually of unsophisticated technology.

### 2.5.2 The Groundwater Provinces of Nigeria

Nigeria has been divided into eleven main hydro-geological provinces not only on geological grounds but also on the basis of groundwater availability, hydraulic behaviour of aquifers and other group characteristics of rock units - Atlas of the Federal Republic of Nigeria. These provinces are as follows:

i) The Coastal Alluvium, and the mangrove and Fresh Water Swamps.

ii) The River Course Alluvium.

iii) The Coastal Sedimentary Lowlands.

iv) The Kerri-Kerri Formation.

v) The Chad basin Confined and Unconfined aquifers.

vi) The Sedimentary Rocks of Sokoto Basin - Cretaceous and Tertiary.

vii) The Middle Niger Basin (Nupe Sandstone).

viii) The Anambra Basin.

ix) The Cross River Basin.

x) The Benue Basin.

xi) The Crystalline Area.

This work is concerned with the availability evaluation of handpump-equipped boreholes in the Crystalline Area of Northern Nigeria.

### 2.5.3 The Crystalline Groundwater Province

The crystalline area covers about 50% of the country's landmass and is made up mainly of the Basement Rock Complex (97%) and the Volcanic rocks which form Plateaux. Groundwater availability in the Basement Complex is very unpredictable

although a high success rate (91.8%) has been recorded in siting boreholes on basement rocks, for the UNICEF assisted "WATSAN Projects" in Gongola and Kwara States, through the use of electromagnetic prospecting methods - de Rooy and Olokun (1986 p.3). The crystalline rocks are by nature impervious but fracturing, fissuring, jointing and weathering may impose secondary aquifer characteristics on the rocks, thus making them favourable to groundwater storage. Recoverable groundwater often occurs in the weathered mantle covering the Basement. Laterite is often developed in the weathered profile and can be locally important as a source of groundwater when its characteristic honey-comb structure is well developed. The gneisses and the granites weather into clayey products which often reduce the permeability and groundwater potential of the weathered materials.

Groundwater in the Basement is essentially unconfined and the water table is restricted to sub-basins; which may be locally hydrologically isolated. Borehole yields vary widely in this area; the average safe yield of the successful ones being of the order of only a few hundred litres per hour. The maximum yield of 4,000 gallons per hour or 18,184.4 litres per hour with a drawdown of 16.3m was recorded for Malumfashi in Katsina area - Atlas of the Federal Republic of Nigeria. Groundwater from the Basement Complex is mostly tapped by hand-dug wells for agricultural and domestic purposes.

The Volcanic rock occur typically in the Biu Plateau with smaller occurrences in the Jos Plateau and other Plateaux dotting the eastern part of the country. Volcanic rocks are mainly

Basalts and groundwater potential in the Basalt Plateau is often high. Boreholes sunk into the Basalts have an average yield of 3,400 gallons or 15,456.7 litres per hour. The quality of the groundwater varies but is generally satisfactory for most domestic uses.

The present day northern Nigerian states that substantially fall within the crystalline groundwater province include: Kano, Jigawa, Kaduna, Katsina, Plateau, Niger, and Kwara.

# CHAPTER THREE
# SYSTEMS ANALYSIS CONCEPTS

## 3.0 SYSTEMS ANALYSIS DEFINITION

In very broad terms, Haith (1982 p. 1) defined systems analysis as the study of a collection of things that function together. He listed the common features of problem solving by a systems approach as follows :

a). Definition of the relevant system and objectives.

b). Generation and evaluation of alternatives for meeting the objectives.

c).Selection of an alternative.

These steps depict logic and with several refinements in their application to problems, unique and often powerful characters are known to emerge.

The selection of an alternative from amongst competing ones often leads to the search for an optimum or best alternative.

This best solution seeking alternative is called optimization.

Some leading authors on the subject of systems analysis for engineering systems, Rau (1970 pp 1-10), Stevens (1979 p. 56) and Haith (1982 pp 6-33) agree that systems analysis can be carried out in a qualitative descriptive fashion but also maintained that quantitative analysis is to be preferred in that it discourages vagueness and reduces subjectivity.

## 3.1 SYSTEMS EVALUATION

WHO (1983 pp 5), defined evaluation as "a systematic way of learning from experience and using the lessons learned both

to improve the functioning, utilization and impact of existing projects". It was also mentioned in the same document that evaluation may focus on one or more of these three stages (functioning, utilization and impact). In this study, the subject of the evaluation that is "availability" comes under the functioning stage.

### 3.1.1 Purposes of Systems Evaluation

Evaluations are essentially to generate feedback from implemented projects and to ensure that past experience is taken into account when new projects are planned. In WHO (1983 p. 5) it was stressed that evaluation should not just list problems and their possible causes but should also include such recommendations as the following ;

a. Actions needed to ;
   (i) get a non-functioning facility into operation
   (ii) improve the performance a functioning facility
   (iii) maximise the utilization of facilities
b. Complementary activities that need to be initiated or emphasized for benefits to materialise or increase;
c. Modifications needed in future projects
d. Actions needed to ensure that lessons learned are conveyed to other programmes and agencies.

## 3.2 MEASURES OF SYSTEMS EFFECTIVENESS

A basic systems analysis procedure is the breaking down of critical issues to the point where actual test measurements and data can be defined.Such basic data however are usually recombined in some way to provide answers to the original

critical issues. These combinations of basic measurements and data are referred to as measures of effectiveness.

Stevens (1979 p. 54) observed that the original idea of a Measure of Effectiveness as a "measure of the degree of effectiveness to which a system achieves a set of specific mission requirements" is deficient. This deficiency he explained, is seen in the fact that such a definition only supplies the answer to only a specific kind of critical issue, namely the kind that asks " How well can the system perform its mission ?" He therefore redefined a Measure of Effectiveness as "any set of criteria established to determine the resolution of critical issue".

Reliability, Maintainability and Availability are examples of measures of systems effectiveness.

## 3.3 RELIABILITY

Reliability has been defined as " the probability of a device performing its purpose adequately for the period of time intended under the operating conditions encountered"- Electronic Industries Association of the United States of America; in Calabro (1962 p.1). This definition gained wide acceptance amongst several reliability authorities.

The four important factors contained in it were also observed in Calabro as: probability, adequate performance, time and operating condition. He noted that while the term probability suggests expression in some quantitative term, (usually a fraction), "adequate performance" demands some established criteria that clearly defines what is to be

considered a satisfactory operation. The third element "time" represents a measure of the time during which the established level of performance can be expected. The fourth factor "operating condition" demands information on the operating environment such as temperature, humidity, shock, vibration and intensity of use.

On the importance of reliability, Calabro also observed (using the example of military equipment) that much is at stake in terms of cost, human life and national security to take any risks with devices which might not function properly when needed most.

Arlosorof et-al (1983 pp 76) observed that the reliability of mechanical equipment is commonly measured in terms of the "Mean Time Before failure (MTBF)" but advocated that equal significance be given to the "Mean Down Time" (that is the average period the equipment is out of service when it breaks down) when assessing the reliability of Community water Supply Systems. In other words, they are advocating the concept of availability as a better means of assessing the reliability of water supply systems. This study adopts the concept of availability.

### 3.3.1 Inherent and Use Reliability

In their study of factors affecting reliability data, The Advisory Group for Reliability of Electronic Equipment - AGREE -(1956), distinguished between two types of reliability namely; Inherent and Use reliability.

This AGREE report also described inherent reliability as a measure of the in-built level of satisfactory performance assurance of an equipment. It is affected by the designers' and manufacturers' selection and application of parts, components, operational parameters mechanical structures, manufacturing techniques and workmanship. Use reliability on the other hand was described as a measure of an equipment's level of satisfactory performance assurance when subjected to the actual conditions of use and operation for which it was designed. Among the major factors that affect use reliability are : Capability of operating and maintenance personnel, operating and maintenance procedures, operational suitability (human engineering) maintainability, auxiliary storage and supporting equipment, installation environment, deterioration in storage and the effects of shipping and handling.

### 3.3.2 Series and Parallel Reliability

These terms refer to the manner in which the components of a system are functionally connected - Calabro (1962 pp 29-37) and Shinners (1976 pp 54-61). The components of a system are functionally in a series if the failure of one of the components causes the failure of the system. In this case, the system is no better than the component with the lowest probability of survival.

When components in series are found to be independent, the reliability of the system can be computed by the application of the mathematical product rule namely ;

$$P_e = (P_1)(P_2)(P_3).....(P_n) \quad \text{--- } Eqn\ 3.1$$

where $P_o$ = probability of satisfactory operation of the system for some specified period of time.

$P_1$, $P_2$, $P_3$ .....$P_n$ = probability of satisfactory operation of the system's components.

n = number of components in the system.

Parallel reliability arises when the components of a system are functionally connected in such a way that when one fails, another will continue with the job. This is often referred to as redundancy and can be justified if the increase in cost due to the additional components is compensated for by increased reliability obtained. Since each units of components in parallel can separately and independently provide for proper operation, the only way the system can fail is if all parallel components fail.

The reliability (P) of components in parallel can therefore be indirectly computed by applying the product rule to the system unreliability U.

$$U = (U_1)(U_2)(U_3).....(U_n) \quad \text{--- } Eqn\ 3.2$$

where $U_1 = U_2 = U_3 ..... = U_n$ = unreliability of each component.

$$\therefore\ U = U_1^n$$

where n = the number of components in parallel

but P + U = 1 ... sum of all probabilities must equal unity

Hence P = 1 - U

$$\therefore\ P = 1 - U_1^n \text{ --- } Eqn3.3$$

3.3.3 Reliability Prediction

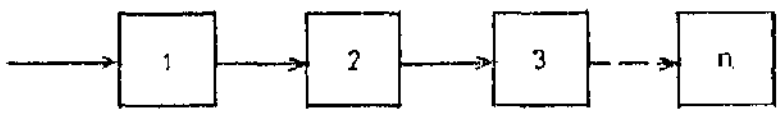
Reliability prediction has been defined as " a method of forecasting the probable reliability of a device by means of past experience or statistical method" - Calabro (1962 pp 208-223) and Blanchard (1991 pp. 77-88). The purpose of reliability prediction is to assist designers and manufacturers of equipments in making early estimates of the reliability of the device during the design stage thus reducing the chances of turning out substandard products.

Reliability prediction could be achieved by any of the following methods :

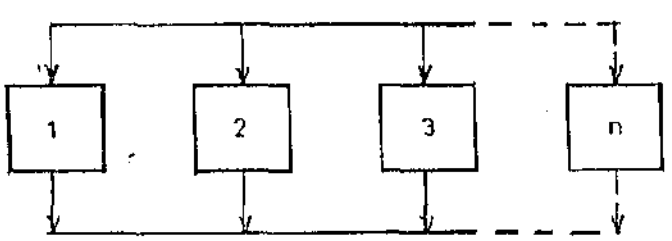
(i) The Guess Method : The guess is based on knowledge of comparable equipment with which the designer is familiar. It is the least desirable method but may be resorted to when there is constraint of time and unavailability of data.

(ii) Mathematical Calculation Method : This is accomplished by applying proven laws of reliability theory to data substantiated by past experiments. Functional diagrams are employed to describe the manner in which the parts of each component and/or components of each system are connected - that is whether in series or in parallel. Figures 3.2 A,B and C are examples of functional diagrams.

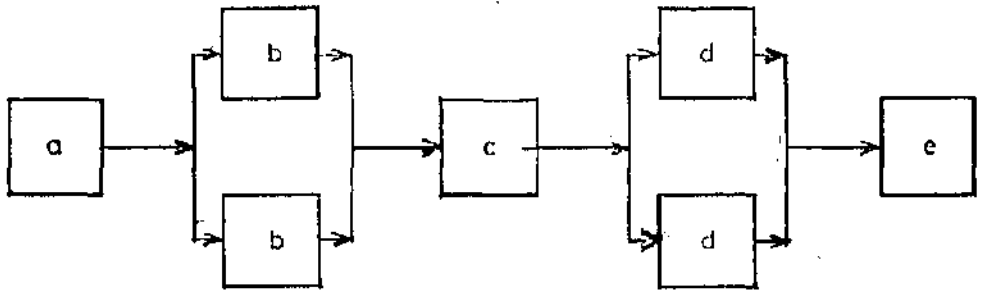
(iii) Measurement Method : Here failure data are accumulated in statistically significant amounts from tests conducted under simulated test conditions in factory or laboratory; form the basis for reliability assessment.




A) Components in Series Connection




B) Components In Parallel Connection




C) Typical System (A Combination of Series and Parallel Connections)

FIG. 3-1 FUNTIONAL DIAGRAMS

The results can then be compared with similar results obtained from prototypes in the field to assure that correlation exists.

### 3.3.4 Gathering Reliability Data - Field Data

Calabro (1962 pp 86-87), reported two basic methods of gathering field failure data as follows :

(i) At random from various installations

(ii) On the basis of controlled programs using data from units functioning under operational conditions in accordance with a fixed routine.

He observed that because of difficulties sometimes encountered in using the above methods, other methods such as simulating field conditions in a laboratory and calculating the system reliability, or determining the failure rates of parts or components under simulated conditions of operation and calculating the system reliability, may be resorted to. Calabro further noted that "there is no known substitute for the actual thing". He listed the factors to be considered in choosing the type of program to be employed in gathering failure data as follows :

(i) degree of assurance required that the data obtained reflect an accurate picture of equipment reliability.

(ii) the amount of data required.

(iii) the period of time over which the data must be accumulated.

(iv) the relative costs of various programs.

Controlled field program or a field and laboratory

combination is considered quite adequate and should be used when time permits. The British Overseas Development Administration funded a research on the reliability of handpumps in which field and laboratory programs were used - Arlosorof et-al (1987 pp 74).
The result of this program is being used in rating the suitability of handpumps for use in rural community water supply.

### 3.3.5 Common Measures of Reliability

Common measures of reliability include failure rate (r), mean time between failures (m) and Probability of survival $P_s$ The expression for probability of survival has also been given as:

$$P_s = e^{-rT} \ldots\ldots \quad Eqn\ 3.4$$

where T = total time in hours

e = base of Napierian or natural logrithm

r = failure rate.

The mean time between failures has also been expressed as:

$$m = \frac{1}{r} \ldots\ldots \quad Eqn\ 3.5$$

## 3.4 MAITAINABILITY

There seem to be no universally accepted definition of maintainability even though there are a number of them in use. The American Department of Defence has defined mantainability as a quality of combined features and characteristics of

equipment design which permits or enhances the accomplishment of maintenance by personnel of average skill under natural and environmental conditions in which it will operate.

As could easily be seen, this definition is broad in concept and does not provide any quantitative basis on which the design engineer could base his judgement. For this reason, the definition suggested by Calabro (1962 pp. 13) and conceptually accepted in Shinners (1976 pp. 66) is found more appropriate for the purpose of this work which aims at quantitative assessment of reliability and maintainability of rural community handpump -equipped boreholes as an input for the system's availability assessment.
This definition states that " maintainability is the probability that a device will be restored to operational effectiveness within a given period of time when the maintenance action is performed in accordance with prescribed procedures".

### 3.4.1 Nature and Importance of Maintainability

From Arlosorof et-al (1987 pp 74-78), maintainability could be seen to consist of two aspects namely : preventive and corrective.

The preventive aspect aims to forestall the occurrence of failure or malfunction by means of preventive methods such as lubrication, cleaning and inspection with corrective action. The corrective aspect arises when a failure or malfunction occurs and a repair is necessary. Both types of maintenance activities result in down time and if a log of

down time is properly kept, the mean time of maintenance action and the maintenance action rate can easily be computed.

$$\Phi = \frac{Totalmaintenance-Actiontime\ (hours)}{Numberofmaitenanceactions} \quad \text{--- } Eqn\ 3.6$$

$$u = \frac{1}{\Phi} \quad \text{---------- } Eqn\ 3.7$$

On the importance of maintainability, Goulden (1990 pp.19-25) observed that delays due to equipment malfunction or failure can have both severe economic and social consequences. This becomes critical in military engineering for example where plans must be made for immediate availability of weapons in case of national emergency.

### 3.4.2 Factors Affecting Maintainability

From Shinners (1976 pp. 66) and Blanchard (1991 pp.88-100) the several factors affecting maintainability may be grouped under two broad headings of design and installation.

Under the factors related to design are : reliability, complexity, interchangeability and replaceability, compatibility, visibility and configuration.

The factors related to installation include : experience, training, skill and supervision of maintenance personnel; techniques used for logistic support, environment, availability of information on equipment overhaul and modification schedule; available test and calibration techniques.

### 3.4.3 Maintainability Equation

The maintainability equation has been expressed as follows :

$$M = (1 - e^{-ut}) \quad \ldots\ldots \; Eqn\ 3.8$$

Where t = maintenance time constraint.

e = base of Napierian or natural logarithm and

$$since\ u = \frac{1}{\Phi}\ ,$$

this may also be written as

$$M = (1 - e^{-t/\Phi}) \ldots\ldots \; Eqn\ 3.9$$

In equation 3.6, the term $e^{-ut}$ is the Poison probability for not performing a repair or maintenance action within the time constraint t, and therefore the term 1 - $e^{-ut}$ must equal the probability of completing the action in this time. Also equation 3.8 shows that the more maintenance action which can be completed within the time interval t, the greater the maintainability. Similarly, from equation 3.9, it can be seen that the smaller the mean time of maintenance action, the greater the maintainability.

### 3.4.4 Maintainability Increment $M_\Delta$

Maintainability increment defines the proportion of failures in time T which will be restored to operational effectiveness in an interval of time t - Calabro (1962 p.122).

Where t = maintenance time constraint

T = reliability test time.

Mathematically expressed, maintainability increment is the product of the probability of one or more failures $P_f$ in time T and the maintainability M for a time constraint t.

$$M_{\Delta} = P_f . M \quad \text{———} \quad \text{Eqn 3.10}$$

$$= (1 - e^{-rT})(1 - e^{-ut})$$

$$= 1 - e^{-rT} - e^{-ut} + e^{-rT}e^{-ut}$$

$$= 1 - e^{-rT} - e^{-ut}(1 - e^{-rT}) \ldots\ldots \text{Eqn 3.11}$$

The calculation of M for a given set of parameters provides a measure of the percentage of total failures in time T, which can be repaired in time t; it is very helpful in computing the availability of a given system.

### 3.5.0 Availability

From Shinners (1976 p. 78), the availability of a system may simply be defined as the probability that the system will be able to perform its intended function when required.

In order to arrive at a more technical definition of availability, Calabro (1962 p. 123) distinguished between equipment and mission availability which he defined respectively as " the probability that a stated percent of equipment or missions will provide adequate performance in time T with no down-time interval exceeding the maintenance time constraint". Calabro further observed that a stated level of availability has two components namely ; reliability and maintainability.

The subject of this study falls within the province of equipment availability.

### 3.5.1 Equipment Availability Models

Two basic mathematical models of equipment availability: the Exponential and the up-Time ratio (UTR) models, have been identified in available literature - Calabro (1962,pp.120 - 125), Shinners (1976, pp 45-68)) and Waterfront (1993 p.4).

**a) The Exponential Model**

The availability is expressed as the sum of the probability of survival $P_s$ and Maintainability increment M .

$$Thus \quad A_E = P_s + M_\Delta \ldots\ldots \; Eqn\ 3.12$$

$$= e^{-rT} + 1 - e^{-rT} - e^{-ut}(1 - e^{-rT})$$

$$= 1 - e^{-ut}(1 - e^{-rT}) \ldots\ldots \; Eqn\ 3.13$$

Where $A_E$ = Equipment Availability

e = Base of Napierian Natural Logarithm

r = Failure rate

t = Maintenance Time Constraint

u = Maintenance action rate

T = Total observation time or test period

Figure 3.2 shows the relationship between equipment availability, probability of survival and maintainability; over a total period of time T. It shows that as T tends to infinity, $P_s$ approaches zero while $A_E$ approaches M. Hence any equipment which is available for use after an extended period of time is the direct result of maintainability or the ability to repair or maintain.

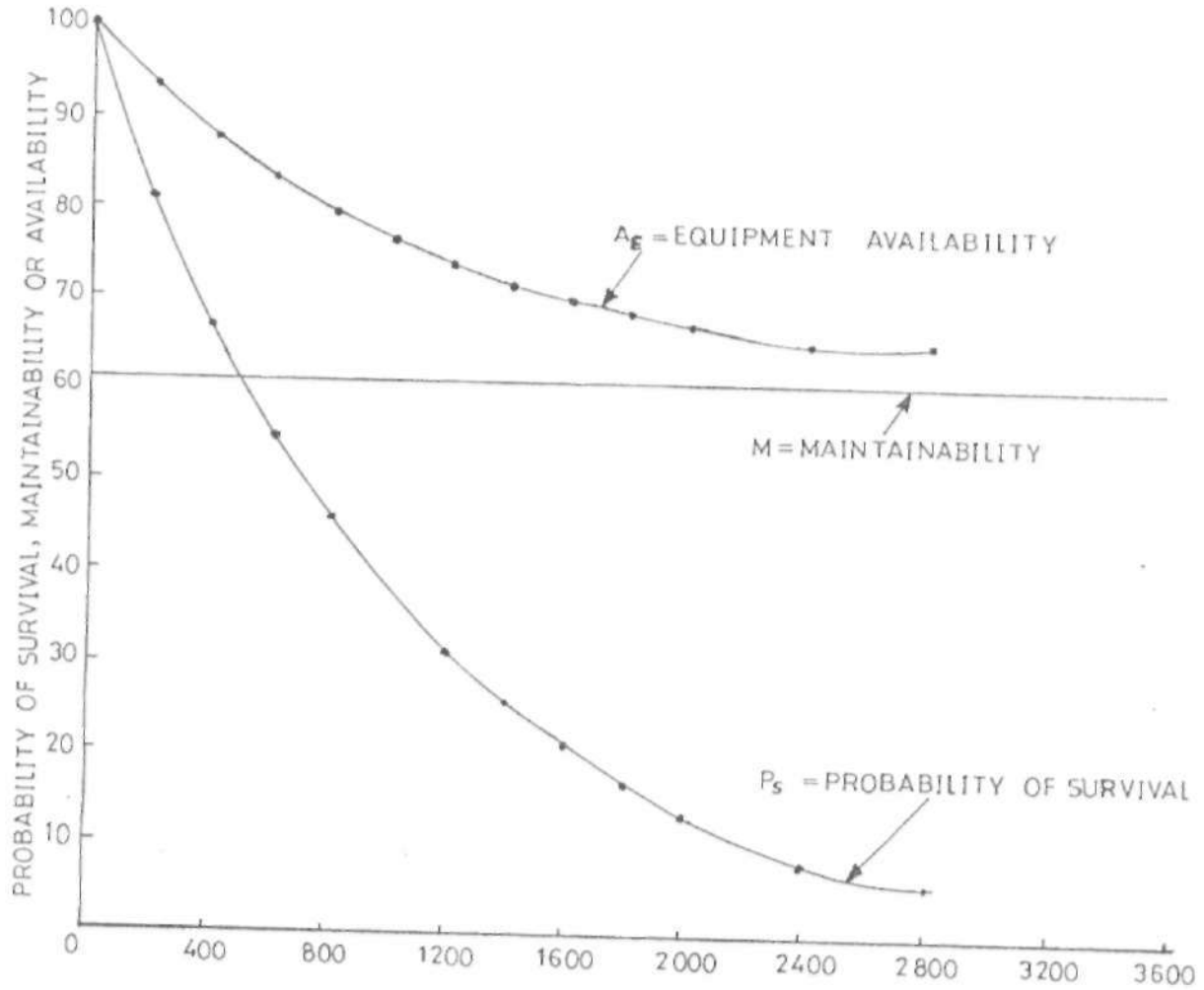



FIG. 3-2 RELATIONSHIP BETWEEN $A_E$, M AND $P_s$ . AVALABILITY MAINTAINABILITY AND PROBABILITY OF SURVIVAL

SOURCE: Adapted from Calabro (1962 P.126) and Blanchard (1991 P.78)

b) The Up-Time Ratio Model

The Up-Time Ratio also known as time availability is another measure of availability commonly applied to continuously operable maintained systems. It defines the percentage of time in a continuum of operating time, for which a system is expected to be in operable state. From Calabro (1962 p. 134), this consists of two components: steady state and transient components. The steady state model is given as

$$UTR = \frac{m}{m+\phi} \quad \ldots\ldots \text{Eqn } 3.14$$

Where UTR = Up-Time ratio

m = Mean time between failures

= Mean time to repair

Since m = 1/r and u = 1/ , equation 3.12 can also be written as:

$$UTR = \frac{u}{r+u} \quad \ldots\ldots \text{Eqn } 3.15$$

Similarly, since the down-time ratio DTR is the ratio of the down-time to the sum of the up and down-times, it may also be written as:

$$DTR = \frac{\phi}{m+\phi} \quad \ldots\ldots \text{Eqn } 3.16$$

OR

$$DTR = \frac{r}{r+u} \quad \ldots\ldots \text{Eqn } 3.17$$

The steady state ratios are not time dependent and do not therefore represent the reliability of a system for any particular time interval. They simply represent the percentage of time in a continuum of operating time, the equipment is

expected to be in operable state (UTR) or will not be functioning (DTR).

On commissioning, it is obvious that the probability of an equipments successful operation at time T is high, when T is small than when it is large. Barlow and Hunter (1960), in Calabro (1962 p. 135), recognised this high probability of success as the contribution of the transient component of the UTR. They gave the complete expression for the UTR and DTR as follows:

$$UTR = \frac{u}{r+u} + \frac{r}{T(r+u)^2} - \frac{r}{T(r+u)^2} \exp[-(r+u)T] \quad \ldots \textit{Eqn } 3.18$$

$$DTR = \frac{r}{r+u} - \frac{r}{T(r+u)^2} + \frac{r}{T(r+u)^2} \exp[-(r+u)T] \quad \ldots . \textit{Eqn } 3.19$$

Equation 3.18 represents a measure of the availability of of the system, since it gives the probability that it will be on at time T.

It should be noticed that as T tends to infinity, the transient state disappears and the general expressions for UTR and DTR reduce to the steady-state conditions of equations 3.16 and 3.17.

### 3.5.2 Availability Prediction

Availability prediction is essentially the process of determining the probable availability of a system at any time T for specified values of failure rate r and maintenance action rate u; or conversely, it is the process of determining the sets of values of u and r that will give a desired availability at any time T.

Two basic steps necessary for effective availability prediction were also pointed out as:

i) Carry out a reliability prediction so as to become cognisant of the effects of failure rate of parts, components and equipment.

ii) Determine the value of u for primary maintenance through simulated time and motion study or by using accepted time measurement standards.

In general it has been observed that stated levels of availability is best achieved by a balance (which takes into consideration the practicalities and cost of the various possibilities in the combination of reliability and maintainability.

### 3.5.3 Availability Standards

It is often necessary to have some reference points or standards on the basis of which the availability of an equipment or system can be assessed. For this purpose therefore Robertson (1969 p. 38) classified equipment and systems into three major groups as follows: normal, operationally vital and prestige.For the normal equipments and systems, an availabilty factor of not less than 0.85 is required, at their full specified performance while for the operationally vital and prestige systems, a factor of not less than o.98 at full specified performance is required. These standards were used in Ibe and Wein (1992 pp. 92-96) for the assessment of the availability of some electronic systems.

# CHAPTER FOUR

## FIELD DATA COLLECTION AND PRESENTATION

### 4.0 BASIC INFORMATION

The questionnaires are of two types "Form A" and "Form B".(appendix A and B). Form A was administered one each to organisation or local government area managing a number of installed boreholes. Form B on the other hand, was administered on each borehole system under evaluation. The objective of the field investigation is to collect data on the operational reliability of the boreholes, over their initial five-year period of operation.

### 4.1 QUESTIONAIRE DISTRIBUTION

The questionnaires were administered in four states within the Crystalline Groundwater Province of Northern Nigeria. These are: Kaduna, Kano, Niger and Kwara. Ten of the Form A were distributed in each of the four states out of which a total of twenty six were properly completed and returned; giving a response rate of 65%. In the case of Form B, direct personal efforts were employed to ensure proper completion of a hundred of the forms in each of the states, from borehole project records. The borehole project records were mainly those of the UNICEF as well as those of the respective states' Rural Water Authority.

### 4.2 DATA PRESENTATION

The information from the questionnaires are presented in the form of tables, histograms and graphs for the purpose of easy

comprehension. Information from Form A are presented together without classification by state because they pertain to general use and maintenance standards. Those from Form B are however classified by state as they relate to individual borehole performance. Topical mode of presentation have been used all through, with columns or rows labelled A,B,C, and D; representing data from Kaduna, Kano, Niger and Kwara states respectively.

### 4.2.1 Maintenance Time Constraint

Table 4.1 presents the responses on maximum tolerable down-time for the borehole units.

Table 4.1 Maintenance Time Constraint

| Maximum Tolerable Down Time | Number of Respondents |
|---|---|
| 0 - 1 Week | 26 |
| 1 - 2 Weeks | - |
| 2 - 3 Weeks | - |
| 3 - 4 Weeks | - |
| 4 - 5 Weeks | - |

### 4.2.2 Shut-Down Time For Routine Maintenance

Table 4.2 presents the responses on usual time spent on routine maintenance.

Table 4.2 Shut-Down Time For Routine Maintenance

| Period | Number of Respondents |
|---|---|
| 0 - 1 Day | 26 |
| 2 - 3 Days | - |
| 4 - 5 Days | - |
| 5 - 6 Days | - |
| 7 Days and above | - |

### 4.2.3 Failure Frequency

Tables 4.3, 4.4, and 4.5 present the component, sub-system and system failure frequencies respectively, for the hundred boreholes studied in each of the states A,B,C and D. Figures 4.1 and 4.2 on the other hand present the comparative sub-system and system failure histograms respectively for the states.

Table 4.3 Component Failure Frequency

| | | Component Failure Frequency in State | | | |
|---|---|---|---|---|---|
| Sub-System | Component | A | B | C | D |
| Well | Platform a | - | 1 | - | 1 |
| | Casing b | 4 | 3 | 3 | 3 |
| | Screen c | 3 | 3 | 3 | 2 |
| | Water Level d | 3 | 3 | 2 | 3 |
| Handpump | Head Assembly e | 9 | 8 | 10 | 11 |
| | Water Tank f | 2 | 3 | 4 | 3 |
| | Stand Assembly g | - | - | - | - |
| | Casing h | - | - | - | - |
| | Riser Pipe i | 16 | 14 | 18 | 23 |
| | Connecting Rod j | 6 | 7 | 6 | 6 |
| | Cylinder Assembly k | 31 | 30 | 31 | 36 |

Table 4.4 Sub-System Failure Frequency

| | Sub-System Failure Frequency in State | | | |
|---|---|---|---|---|
| Sub-System | A | B | C | D |
| Well | 10 | 10 | 8 | 9 |
| Handpump | 64 | 62 | 69 | 81 |

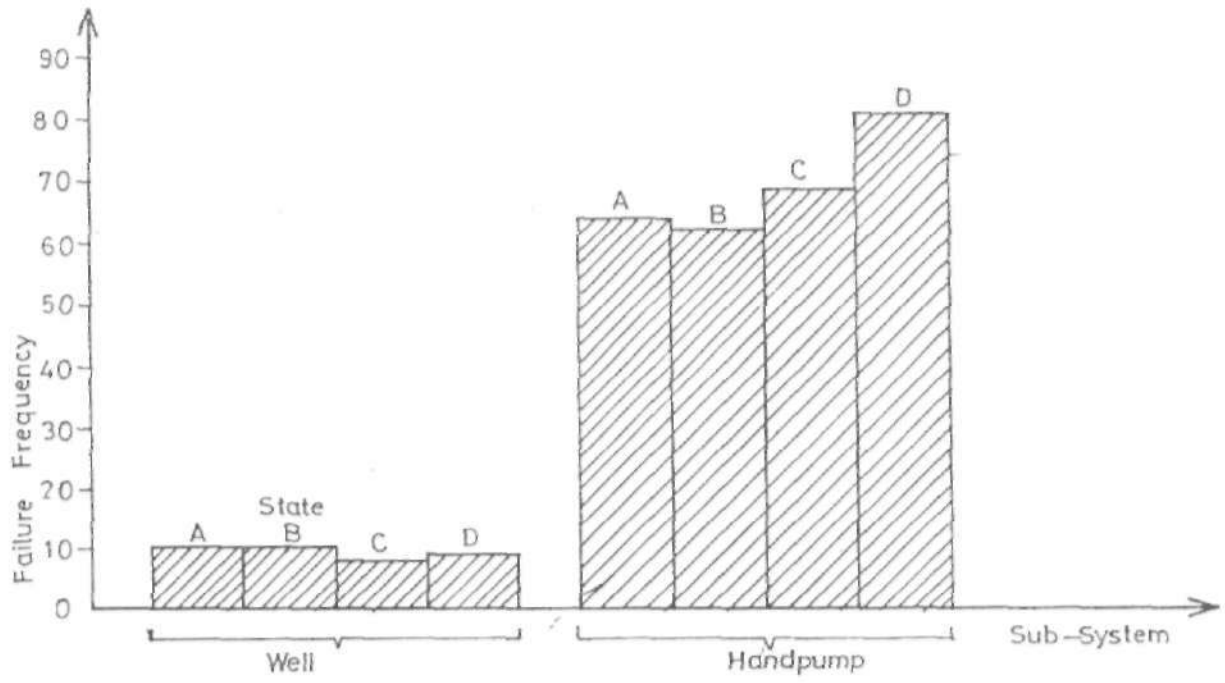



FIG 4·1 Comparative Sub-System Failure Histogram

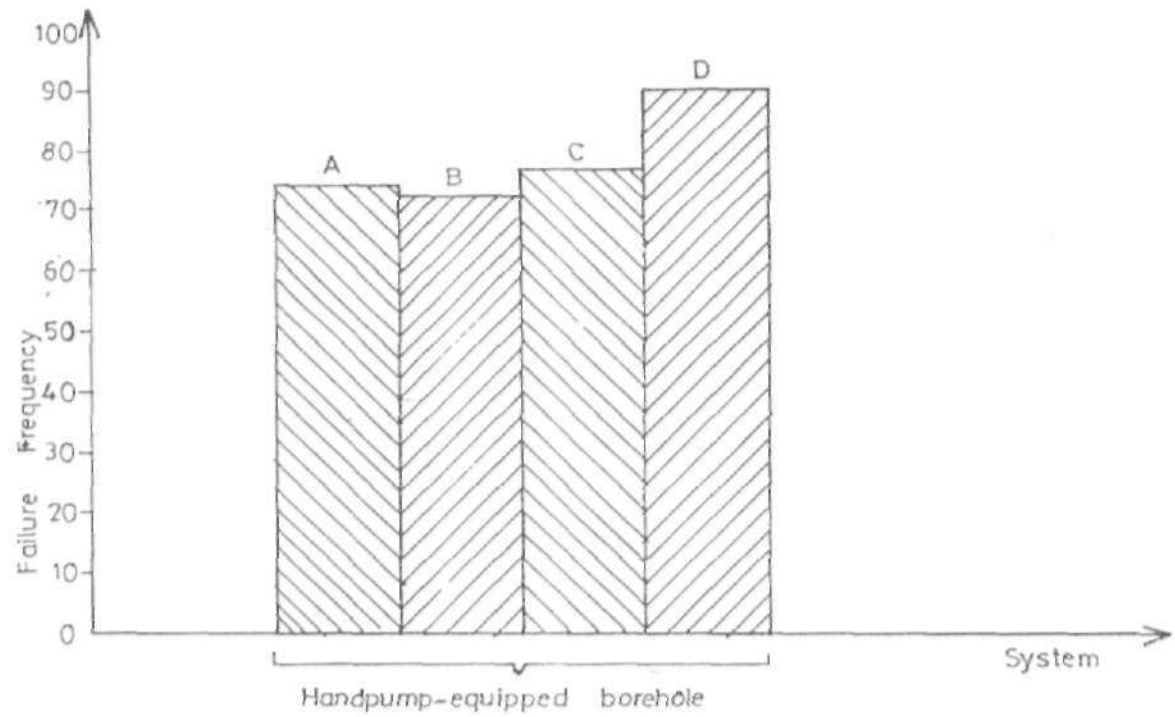



FIG 4·2 Comparative System Failure Histogram

Table 4.5 System Failure Frequency

| | System Failure Frequency in State | | | |
|---|---|---|---|---|
| System | A | B | C | D |
| Handpump-Equipped Borehole | 74 | 72 | 77 | 90 |

### 4.2.4 Probability of Survival Computation

Table 4.6 is a typical example of the computation for the probability of survival of the one hundred installed boreholes over the initial five-year period of operation in each of the four states. Table 4.7 shows the results of the computation for the four states.

Table 4.6 Probability of Survival For The 100 Installed Boreholes in State A

| Column 1<br>Year | Column 2<br>No. of Failed Units | Column 3<br>No. of Survivors | Column 4<br>Probability of Survival $P_s = \frac{Column3}{100}$ |
|---|---|---|---|
| 0 | | 100 | 1.00 |
| 1 | 6 | 94 | 0.94 |
| 2 | 9 | 85 | 0.85 |
| 3 | 15 | 70 | 0.70 |
| 4 | 6 | 64 | 0.64 |
| 5 | 3 | 61 | 0.61 |

Table 4.7 Probability of Survival Results For The Four States

| | Probability of Survival in Year | | | | | |
|---|---|---|---|---|---|---|
| State | 0 | 1 | 2 | 3 | 4 | 5 |
| A | 1.00 | 0.94 | 0.85 | 0.70 | 0.64 | 0.61 |
| B | 1.00 | 0.94 | 0.81 | 0.70 | 0.61 | 0.57 |
| C | 1.00 | 0.95 | 0.83 | 0.71 | 0.66 | 0.62 |
| D | 1.00 | 0.95 | 0.78 | 0.62 | 0.58 | 0.52 |

### 4.2.5 Maintainability And Maintainability Increment Computation and Results

Table 4.8 shows the computation for the Maintainability and maintainability increment for the 100 boreholes in one of the states under study, while Tables 4.9 and 4.10 show the maintainability and maintainability increment results respectively, for the four states.

Table 4.8 Maintainability/Maintainability Increment For The Boreholes in State A.

| Column 1<br>Year | Column 2<br>Probability of failure<br>$P_f = (1 - P_s)$ | Column 3<br>Number of failures | Column 4<br>Number Restored within one week | Column 5<br>Maintainability<br>$M = \frac{Col3}{Col4}$ | Column 6<br>Maintainability Increment<br>$M_\Delta = P_F.M$ |
|---|---|---|---|---|---|
| 0 | 0 | | | | 0.00 |
| 1 | 0.06 | 6 | 3 | 0.50 | 0.03 |
| 2 | 0.15 | 10 | 6 | 0.60 | 0.09 |
| 3 | 0.30 | 23 | 13 | 0.57 | 0.17 |
| 4 | 0.36 | 18 | 11 | 0.61 | 0.22 |
| 5 | 0.39 | 17 | 10 | 0.59 | 0.23 |

Table 4.9 Maintainability Results For The Four States

| State | Maintainability Within Year | | | | |
|---|---|---|---|---|---|
| | 0 - 1 | 1 - 2 | 2 -3 | 3 - 4 | 4 - 5 |
| A | 0.50 | 0.60 | 0.57 | 0.61 | 0.59 |
| B | 0.57 | 0.50 | 0.57 | 0.56 | 0.58 |
| C | 0.57 | 0.60 | 0.62 | 0.58 | 0.53 |
| D | 0.67 | 0.65 | 0.59 | 0.57 | 0.58 |

Table 4.10 Maintainability Increment Results For The Four States

| State | Maintainability Increment Results in Year | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 |
| A | 0.00 | 0.03 | 0.09 | 0.17 | 0.22 | 0.23 |
| B | 0.00 | 0.03 | 0.10 | 0.17 | 0.22 | 0.25 |
| C | 0.00 | 0.03 | 0.10 | 0.18 | 0.20 | 0.20 |
| D | 0.00 | 0.03 | 0.14 | 0.22 | 0.24 | 0.28 |

### 4.2.6 Availability Computation and Results

Table 4.11 is a typical example of the computation for the availability over the initial five-year period of the one hundred boreholes under study in each of the four states. Table 4.12 on the the other hand shows the computed values of the availability in each of the four states.

Table 4.11 Availability of The Boreholes in State A

| Year | Probability of Survival $P_s$ | Maintainability Increment $M_\Delta$ | Availability $A = (P_s + M_\Delta)$ |
|---|---|---|---|
| 0 | 1.00 | 0.00 | 1.00 |
| 1 | 0.94 | 0.03 | 0.97 |
| 2 | 0.85 | 0.09 | 0.94 |
| 3 | 0.70 | 0.17 | 0.87 |
| 4 | 0.64 | 0.22 | 0.86 |
| 5 | 0.61 | 0.23 | 0.84 |

Table 4.12 Availability Results For The States

| State | Availability in Year | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 |
| A | 1.00 | 0.97 | 0.94 | 0.87 | 0.86 | 0.84 |
| B | 1.00 | 0.97 | 0.91 | 0.87 | 0.83 | 0.82 |
| C | 1.00 | 0.98 | 0.93 | 0.89 | 0.86 | 0.82 |
| D | 1.00 | 0.98 | 0.92 | 0.82 | 0.82 | 0.80 |

Figures 4.3 to 4.6 show the graphs of probability of survival, maintainability and availability of the boreholes investigated in each of the four states.

4.2.7 Down-Times And Repair Times For The failed Borehole Units

Table 4.13 summarises the results for the four states, of the total down-times (in weeks) for each of the failed borehole units, while table 4.14 does same for the total repair times.

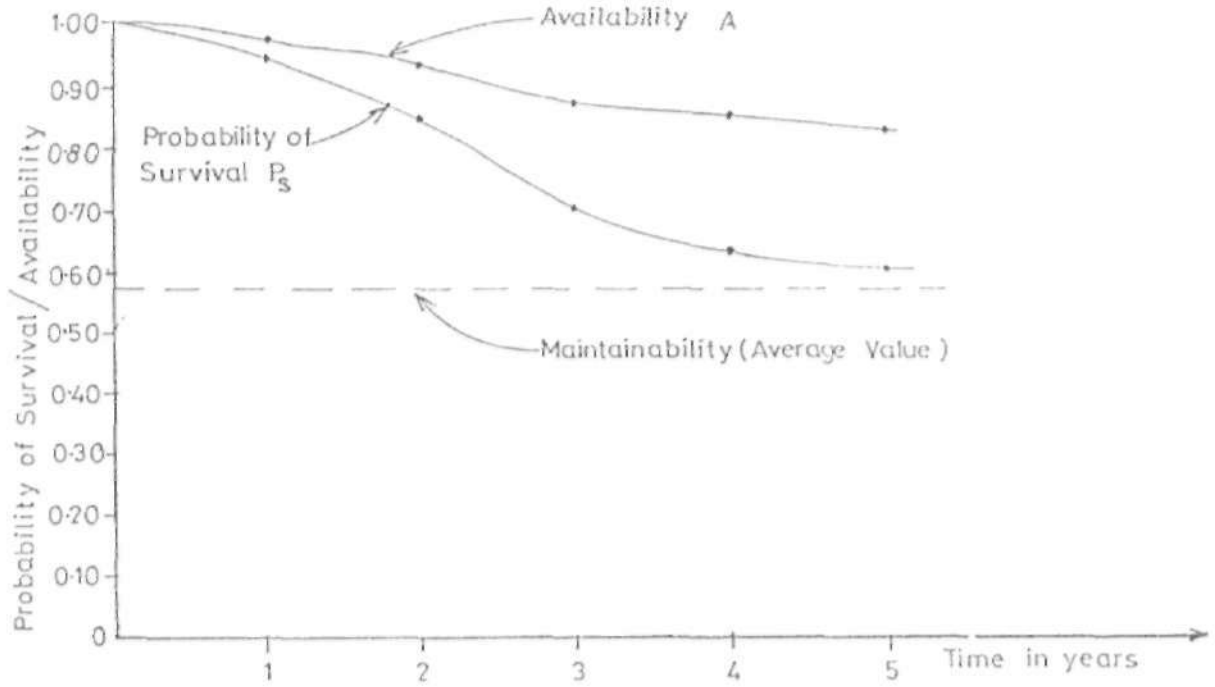



FIG 4·3 Availability and Probability of Survival Curves ( For State A )

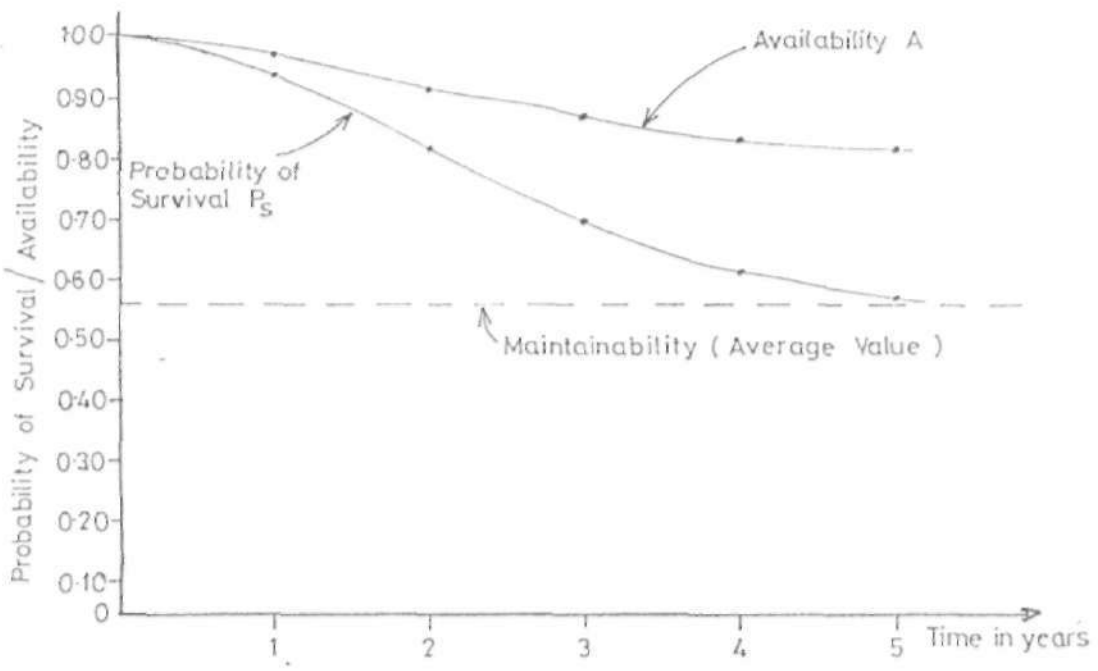



FIG 4·4 Availability and Probability of Survival Curves ( For State B )

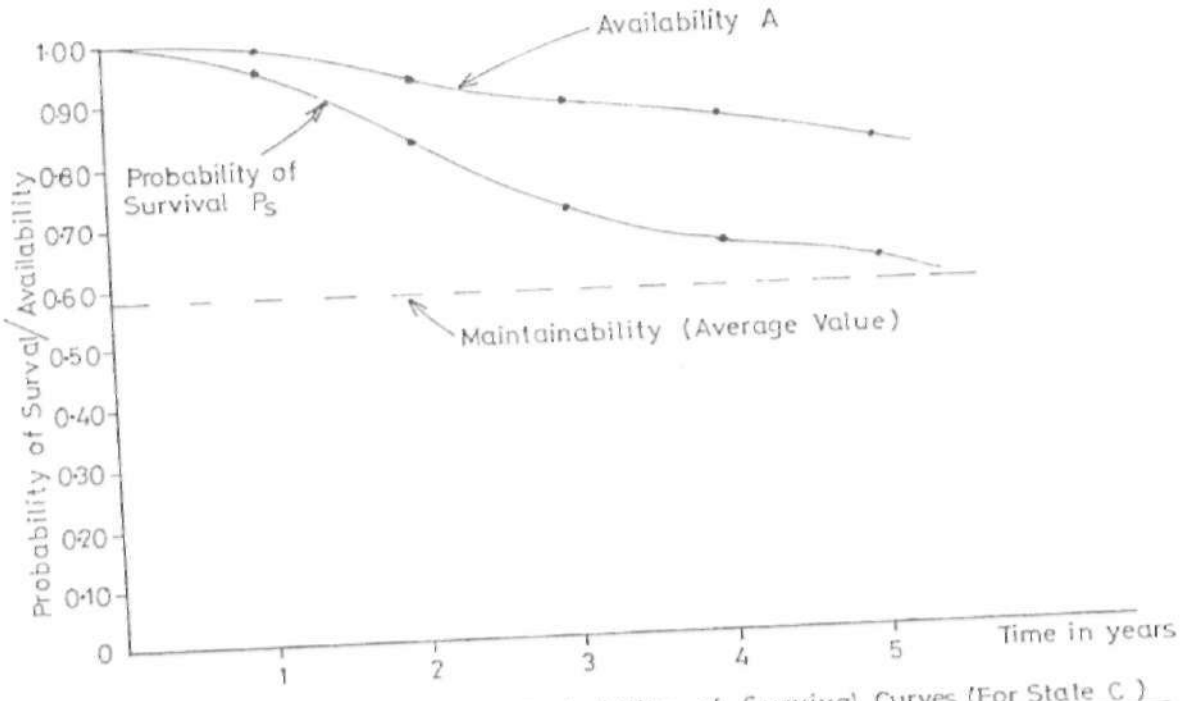



FIG 4·5 Availability and Probability of Survival Curves (For State C)

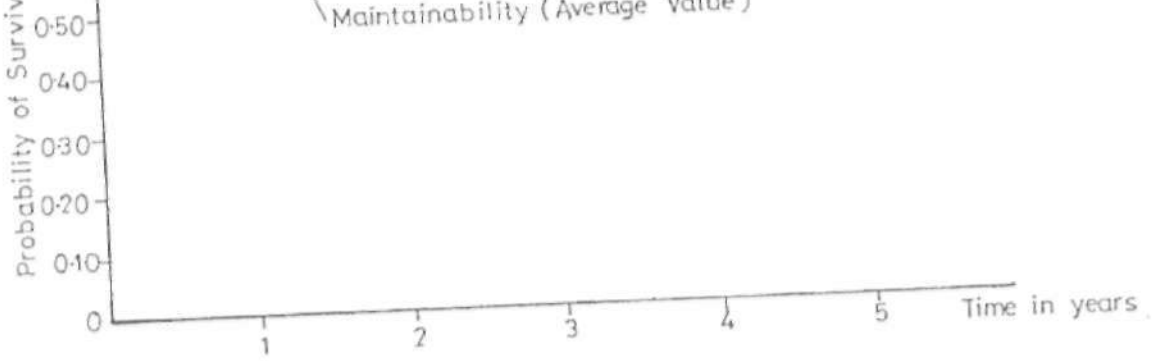



FIG 4·6 Availability and Probability of Survival Curves (For State D)

Table 4.13 Total Down-Times: Summary of Results For The Four States

| State | Parameters | | | | |
|---|---|---|---|---|---|
| | Range | Mean ($\overline{X}$) | Standard Dev. (S) | 95% C.I. For The Mean | |
| | | | | Lower Bound | Upper Bound |
| A | 4.86 | 2.14 | 1.15 | 1.78 | 2.50 |
| B | 6.71 | 2.49 | 1.62 | 2.01 | 2.97 |
| C | 2.72 | 1.79 | 0.69 | 1.57 | 2.01 |
| D | 18.14 | 2.79 | 3.50 | 1.80 | 3.78 |

Table 4.14 Total Repair-Times: Summary of Results For The Four States

| State | Parameters | | | | |
|---|---|---|---|---|---|
| | Range | Mean ($\overline{X}$) | Standard Dev. (S) | 95% C.I. For The Mean | |
| | | | | Lower Bound | Upper Bound |
| A | 16.00 | 6.26 | 3.13 | 5.28 | 7.24 |
| B | 18.40 | 5.77 | 2.93 | 4.89 | 6.25 |
| C | 10.50 | 6.23 | 2.68 | 5.38 | 7.08 |
| D | 13.50 | 5.29 | 2.58 | 4.56 | 6.02 |

### 4.2.8 Up-Time Ratios For The Failed Borehole Units

Table 4.15 gives the summary of results of up-time ratios in weeks per year for the failed borehole units in each of the four states under study.

Table 4.15 Up-Time Ratio - Summary of Results For The Four States

| State | Parameters | | | | |
|---|---|---|---|---|---|
| | Range | Mean ($\bar{X}$) | Standard Dev. (S) | 95% C.I. For The Mean | |
| | | | | Lower Bound | Upper Bound |
| A | 0.97 | 51.57 | 0.23 | 51.50 | 51.64 |
| B | 1.34 | 51.50 | 0.32 | 51.40 | 51.60 |
| C | 0.55 | 51.65 | 0.13 | 51.61 | 51.69 |
| D | 3.74 | 51.42 | 0.70 | 51.22 | 51.62 |

4.2.9 Time to First Failure - Summary of Results For The Four States

Table 4.16 summarises the results of the time to first failure of the failed borehole units in each of the four states studied.

Table 4.16 Time to First Failure - Summary of Results Fr The Four States

| State | Parameters | | | | |
|---|---|---|---|---|---|
| | Range | Mean ($\bar{X}$) | Standard Dev. (S) | 95% C.I. For The Mean | |
| | | | | Lower Bound | Upper Bound |
| A | 196.14 | 120.25 | 54.77 | 106.06 | 137.44 |
| B | 226.00 | 115.22 | 60.67 | 97.09 | 133.35 |
| C | 193.72 | 118.12 | 56.54 | 100.14 | 94.27 |
| D | 230.43 | 111.13 | 59.58 | 136.10 | 127.99 |

# CHAPTER FIVE

## FIELD DATA ANALYSIS AND DISCUSSION

### 5.0 ANALYSIS CONCEPT

Statistical and/or mathematical tools namely, anlysis of variance, chi-square tests, curve fitting tests and graphical analysis, are applied on the field data of chapter four. The purpose is to identify and collate important features implicit in the data.

### 5.1 FAILURE FREQUENCIES

5.1.1 Component Failure Frequency. The fundamental question is whether component failure frequency is the same in the four states under study? This question is answered by means of hypothesis testing involving a one-way analysis of variance (ANOVA) of the data of Table 4.3. The important features of this test are presented below and the details of the procedure for the analysis of variance is presented in appendix D.

Null Hypothesis $H_0$: Component failure frequency is the same in the four states.

Alternative Hypothesis $H_A$: Component failure is not the same in the four states.

Test Statistic: F_ratio

Rejection Criterion: Reject $H_0$ if F_ratio > $F_{0.95}$ otherwise accept $H_0$.

Table 5.1 One-Way ANOVA For The Component Failure Frequency Results of Table 4.3

| Source | Sum of Squares | Degree of Freedom (d.f) | Mean-Square | F-ratio | $F_{0.95}$ |
|---|---|---|---|---|---|
| Treatment | (SST) 17.88 | 1 | 5.95 | 0.061 | 2.84 |
| Residual | (SSE) 3812.55 | 40 | 95.31 | | |
| Total | (SS) 3830.43 | 43 | | | |

From Table 5.1, F-ratio < $F_{0.95}$ (0.061 < 2.84).

Accept $H_0$.

Conclusion: Component failure frequency is the same in the four states.

A close look at Table 4.3 also reveals the same component failure pattern for all the states. The cylinder assembly has the highest failure frequency (about 40% of the total system failure), followed by riser pipe with about 22% and the head assembly with about 12%. No failure was recorded in any of the states for the stand assembly and casing components of the handpump sub-system.

### 5.1.2 Sub-System Failure Frequency

It is intended to check whether or not there is a significant difference in the sub-system failure frequency of the four states. For this purpose, a one-way analysis of variance of the data of Table 4.4 is used to test this hypothesis as shown below.

$H_0$: Sub-system failure frequency is the same in all the four states.

$H_A$: Sub-system failure frequency is different in the four

states.

Test Statistic: F-ratio

Table 5.2 One-Way ANOVA For The Sub-System Failure Frequency Results of Table 4.4

| Source | Sum of Squares | Degree of Freedom (d.f) | Mean-Square | F-ratio | $F_{0.95}$ |
|---|---|---|---|---|---|
| Treament | (SST) 98.38 | 3 | 32.79 | 0.02 | 6.59 |
| Residual | (SSE) 6917.50 | 4 | 1729.38 | | |
| Total | (SS) 7015.88 | 7 | | | |

From Table 5.2, F-ratio < $F_{0.95}$ (0.02 < 6.59).

Accept $H_o$.

Conclusion: There is no significant difference between the sub-system failure frequencies of the four states.

Table 4.4 shows that the handpump has a much higher failure frequency (88% approx. of the system failure), than the well.

### 5.1.3 System Failure Frequency

The hypothesis that the system failure frequency is the same in all the four states is tested. The Chi-square test is applied on the data of Table 4.5 as presented below.

$H_o$: System failure frequency is the same in the four states.

$H_A$: System failure frequency is different in the four states.

Test Statistic:

$$X^2 = \sum \frac{(O_i - e_i)^2}{e_i}$$

with degree of freedom (V) = K - 1

where $O_i$ = Observed frequency

$e_i$ = Expected frequency

K = Number of categories or classes

Acceptance criterion: Accept $H_o$ if the calculated $X^2$ ($X^2_{cal.}$) is less than the tabulated $X^2$ at 0.5% level of significance and V degrees of freedom; that is

$$X^2_{cal.} < X^2_{0.05,V}$$

Table 5.3 Chi-Square Computation For The System Failure Frequency

| State | $O_i$ | $e_i$ | $O_i - e_i$ | $\frac{(O_i - e_i)^2}{e_i}$ |
|---|---|---|---|---|
| A | 74 | 78.25 | -4.25 | 0.231 |
| B | 72 | 78.25 | -6.25 | 0.499 |
| C | 77 | 78.25 | -1.25 | 0.020 |
| D | 90 | 78.25 | 11.75 | 1.764 |
| Total | 313 | | | $X^2 = 2.514$ |

Note: $e_i = 313/4 = 78.25$

$V = 4 - 1 = 3$

$X^2_{cal.} = 2.514$

$X^{20.05,3} = 7.81$

Accept $H_o$

Conclusion: System failure frequency is the same for the four states.

## 5.2 PROBABILITY OF SURVIVAL

### 5.2.1 Probability of Survival in Each of The Four States

A one-way analysis of variance is performed on the data of Table 4.7, in a procedure similar to that of section 5.11.

$H_o$: Probability of survival is the same in the four states.

$H_A$: Probability of survival is different in the four states.

Test Statistic: F-ratio

Table 5.4 One-Way ANOVA For The Probability of Survival Results of Table 4.7

| Source | Sum of Squares | Degree of Freedom (d.f) | Mean-Square | F-ratio | $F_{0.95}$ |
|---|---|---|---|---|---|
| Treament | (SSB) 0.01 | 3 | 0.002 | 0.06 | 3.10 |
| Residual | (SSE) 0.61 | 20 | 0.034 | | |
| Total | (SS) 0.62 | 23 | | | |

From Table 5.4, F-ratio < $F_{0.95}$ (0.06 < 3.10).

Accept $H_0$.

Conclusion: Probability of survival is the same in the four states.

5.2.2 Modelling The Probaility of Survival Field Data

This problem is appproached by means of a curve fitting analysis using the probability of survival data of Table 4.7. It would be recalled that from equation 3.4 , the probability of survival is given by:

$$P_s = e^{-rT}$$

Hence $InP_s = -rT$

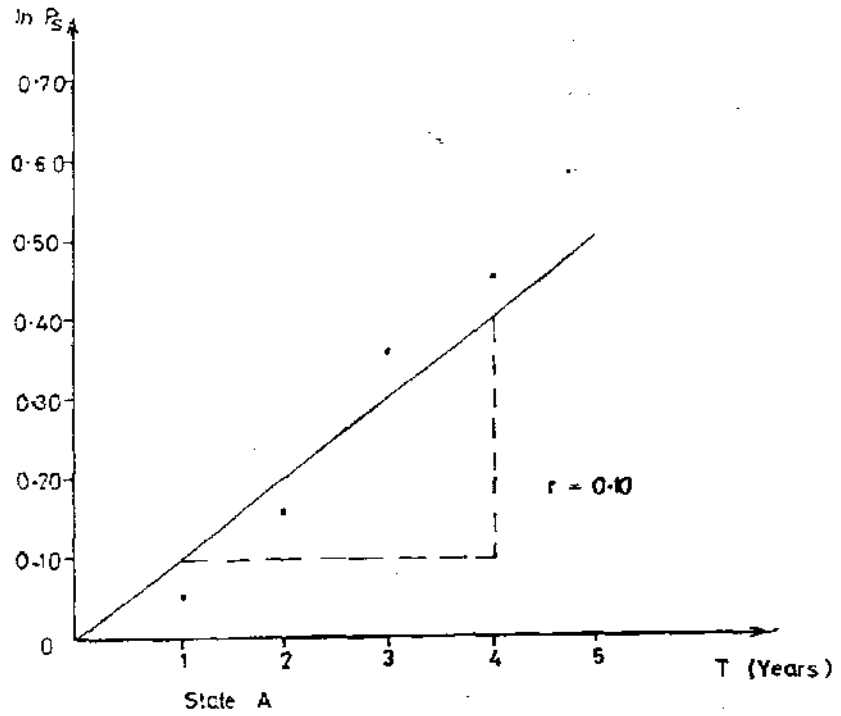
or $- InP_s = rT$.

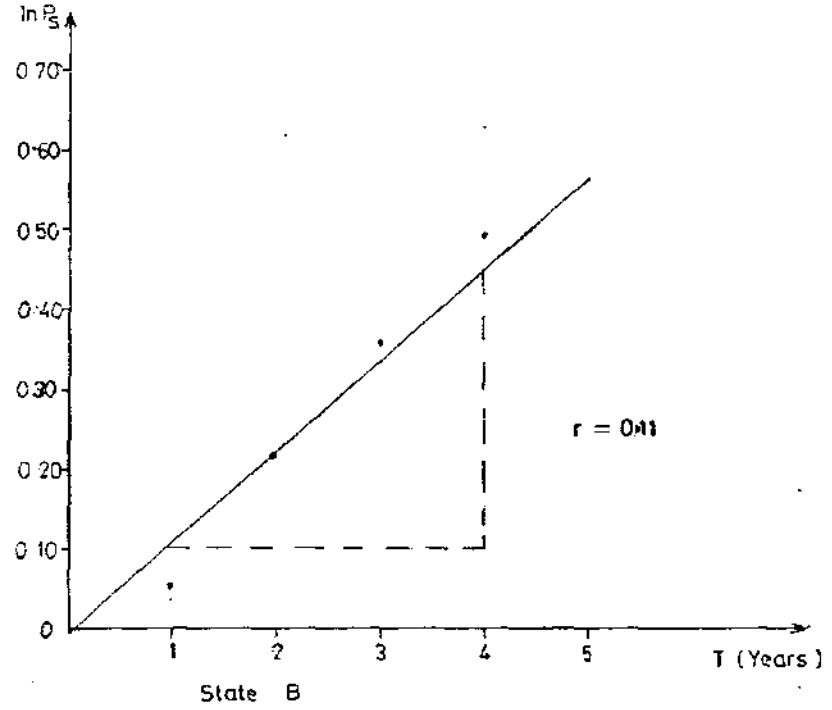
Thus plotting $-InP_s$ against the time T, for each of the states A, B, C and D in Table 4.7, should in each case, produce a straight line (or its approximate) with a gradient equal in magnitude to the failure rate r. Otherwise, the field data does not fit into the theoretically assumed exponential model.

$$\frac{0.10+0.10+0.11+0.13}{4} = 0.11$$

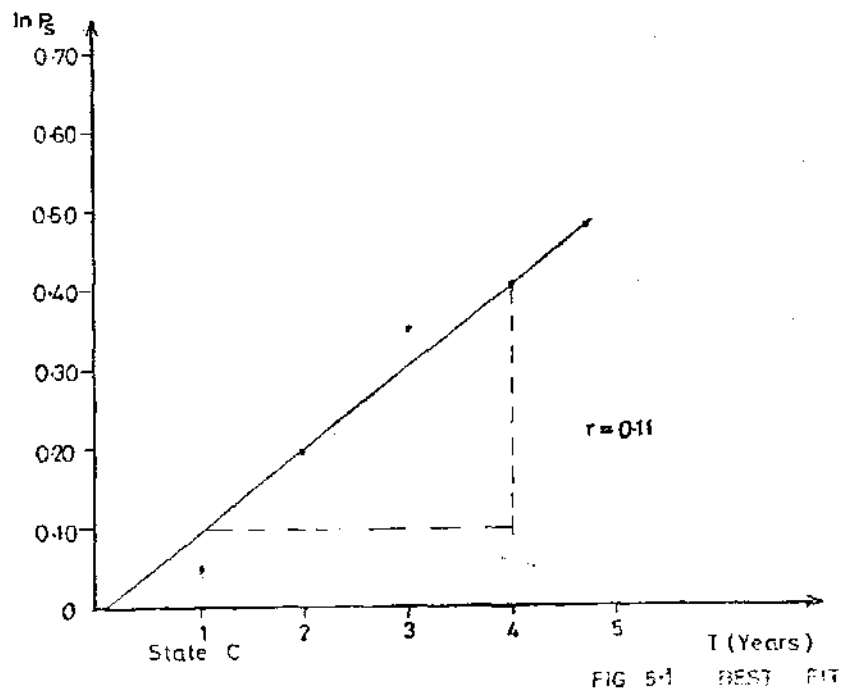
Tables 5.5, A to D and figures 5.1, A to D, show the computations and results respectively, of the curve fitting analysis from which conclusion is reached, that the field data satisfactorily fits into the exponential model. The average failure rate may also be seen as equal to:

One good implication of the results of sections 5.2.1 and 5.2.2 is that the probability of survival can be estimated with a good level of confidence for handpump-equipped boreholes in the Crystalline Groundwater Province of Northern Nigeria. This is the subject of discussion in section 5.2.3.




C



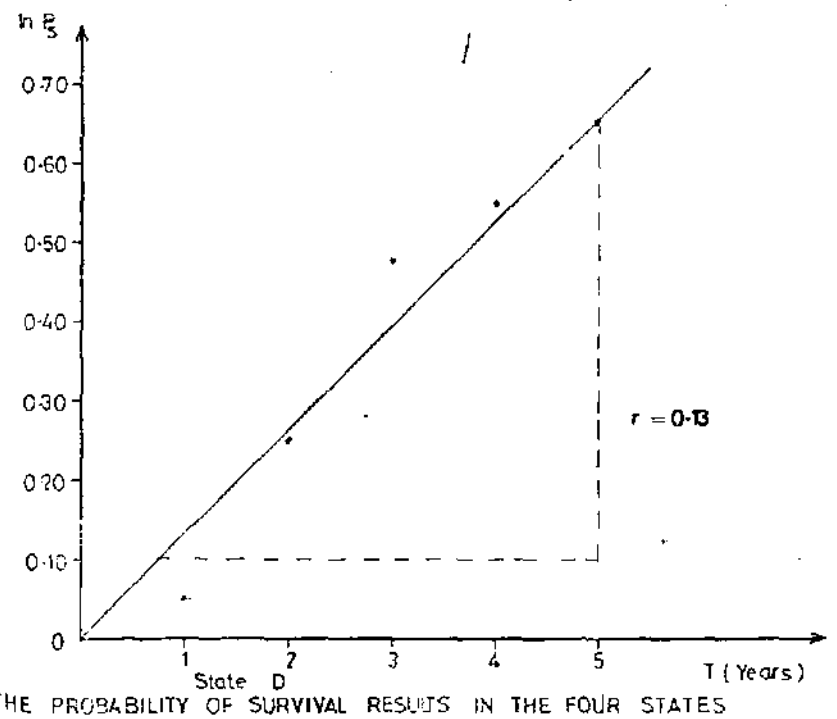




FIG 5·1 BEST FIT LINE FOR THE PROBABILITY OF SURVIVAL RESULTS IN THE FOUR STATES

Table 5.5, A-D. Curve Fitting Computations For The Probability Of Survival Data Of Table 4.7

(A)

| T (Years) | $P_s$ | $-InP_s$ |
|---|---|---|
| 0 | 1.00 | 0.000 |
| 1 | 0.94 | 0.062 |
| 2 | 0.85 | 0.163 |
| 3 | 0.70 | 0.357 |
| 4 | 0.64 | 0.446 |
| 5 | 0.61 | 0.494 |

(B)

| T (Years) | $P_s$ | $-InP_s$ |
|---|---|---|
| 0 | 1.00 | 0.000 |
| 1 | 0.94 | 0.062 |
| 2 | 0.81 | 0.211 |
| 3 | 0.70 | 0.357 |
| 4 | 0.61 | 0.494 |
| 5 | 0.57 | 0.562 |

(C)

| T (Years) | $P_s$ | $-InP_s$ |
|---|---|---|
| 0 | 1.00 | 0.000 |
| 1 | 0.95 | 0.051 |
| 2 | 0.83 | 0.186 |
| 3 | 0.71 | 0.342 |
| 4 | 0.66 | 0.416 |
| 5 | 0.62 | 0.478 |

(D)

| T (Years) | $P_s$ | $-InP_s$ |
|---|---|---|
| 0 | 1.00 | 0.000 |
| 1 | 0.95 | 0.051 |
| 2 | 0.78 | 0.248 |
| 3 | 0.62 | 0.478 |
| 4 | 0.58 | 0.544 |
| 5 | 0.52 | 0.654 |

### 5.2.3 Probability Of Survival Prediction Over The 20-Year Assumed Design Life Of The Handpump-Equipped Borehole.

In section 5.2.2, the theoretical model for the probability of survival was confirmed with the field data. The average failure rate r was also evaluated as 0.11, and can be used in the model to estimate the values of $P_s$ for
T = 1 ,2, 3,.... up to 20 years. The result is shown in table 5.6 and figure 5.2.

Table 5.6 Predicted Values Of Probability Of Survival Over A 20-Year Time Period

| T (Years) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| -rT | 0 | -0.11 | -0.22 | -0.33 | -0.44 | -0.55 | -0.66 | -0.77 |
| $P_s = e^{-rT}$ | 1 | 0.90 | 0.80 | 0.71 | 0.64 | 0.58 | 0.52 | 0.46 |

| T (Years) | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|
| -rT | -0.88 | -0.99 | -1.10 | -1.21 | -1.32 | -1.43 | -1.54 | -1.65 |
| $P_s = e^{-rT}$ | 0.41 | 0.37 | 0.33 | 0.30 | 0.27 | 0.24 | 0.21 | 0.19 |

| T (Years) | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|
| -rT | -1.76 | -1.87 | -1.98 | -2.09 | -2.20 |
| $P_s = e-rT$ | 0.17 | 0.15 | 0.14 | 0.12 | 0.11 |

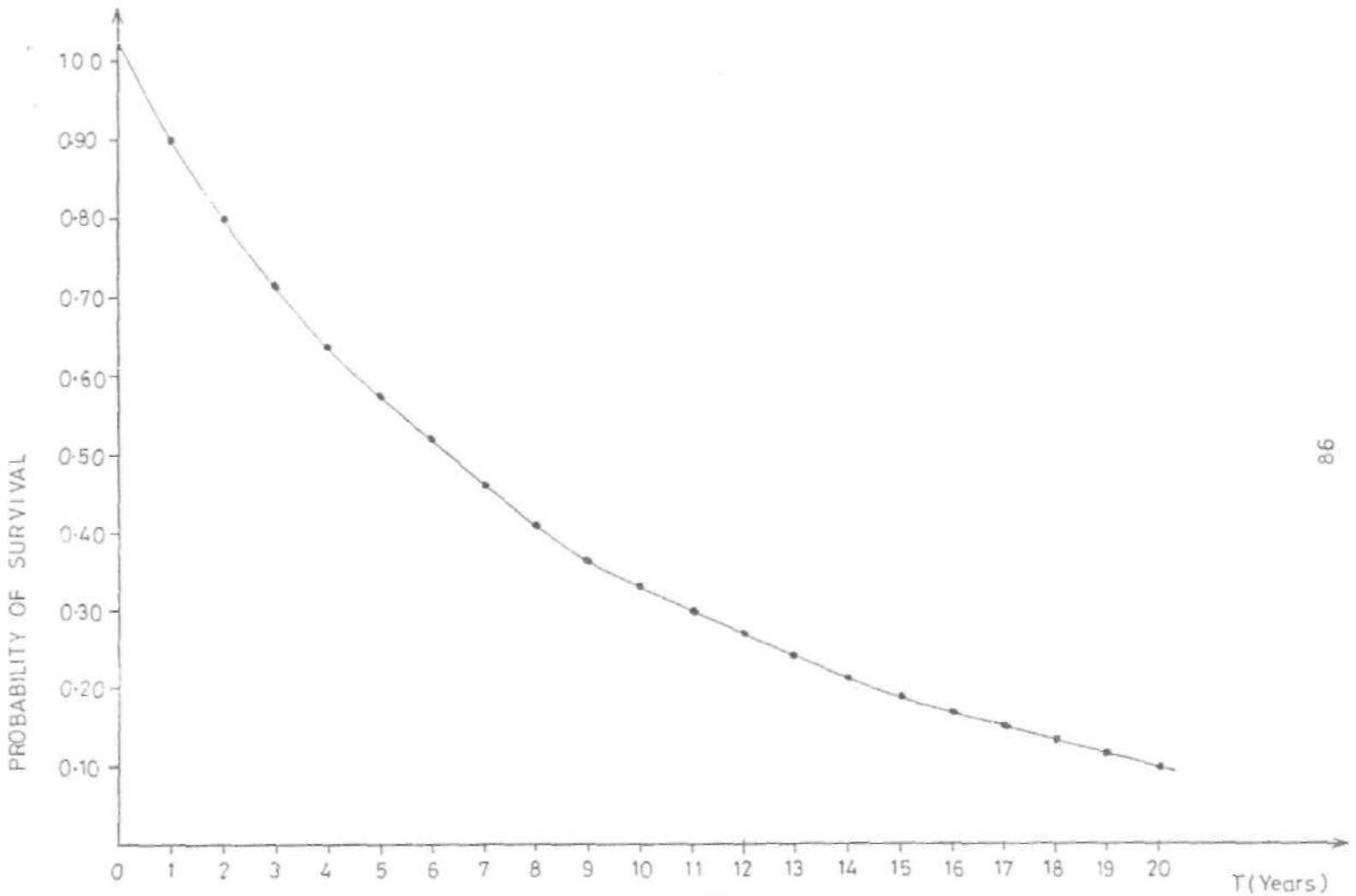



FIG. 5·2 ESTIMATED VALUES OF PROBABILITY OF SURVIVAL OVER A 20 YEAR PERIOD OF TIME

## 5.3 MAINTAINABILITY AND MAINTAINABILITY INCREMENT

### 5.3.1 Maintainability

The issue here is the twin task of ascertaining whether or not maintainability is the same in the four states, and also whether or not it is the same for each of the five time periods observed. A test of hypothesis involving a two-way analysis of the variance of the maintainability data of Table 4.9, is used to resolve the task, as presented below.

Table 5.7 A Two-Way ANOVA For The Maintainability Results Of Table 4.9

| Source | Sum of Squares | Degree of Freedom (d.f) | Mean-Square | F-ratio | $F_{0.95}$ |
|---|---|---|---|---|---|
| Treament | (SST) 0.00 | 4 | 0.000 | 0.00 | 3.26 |
| Block | (SSB) 0.01 | 3 | 0.003 | 0.15 | 3.49 |
| Residual | (SSE) 0.02 | 12 | | | |
| Total | (SS) 0.03 | 19 | | | |

a) Test 1

$H_0$: Maintainability is the same in the four states

$H_A$: Maintainability is not the same in the four states

Test Statistic: F - ratio

From Table 5.7, and with respect to the block (SSB), F-ratio < $F_{0.95}$ (0.15 < 3.49).

Accept $H_0$

Conclusion: Maintainability is the same in the four states.

b) Test 2

$H_0$: Maintainability is the same for the five periods

studied.

$H_A$: Maintainability is not the same for the five periods studied.

Test Statistic: F-ratio

From Table 5.7, and with respect to the treatment (SST),

F- ratio < $F_{0.95}$ (0 < 3.26).

Accept $H_0$

Conclusion: Maintainability is the same for the five time periods.

From the conclusions of tests 1 and 2 above, the maintainability of handpump-equipped boreholes can be assumed constant for the province studied. Plotting maintainability against time will therefore result in a straight line parallel to the X axis. This agrees with the theoretical maintainability function of figure 3.2. For this work, the constant maintainability value is taken as the average of the results recorded in Table 4.9, that is 0.58.

### 5.3.2 Maintainability Increment

The primary concern here is to ascertain whether there are significant differences in the maintainability increment results of the four states. This is effected by means of a one-way analysis of variance of the maintainability increment data of Table 4.10.

$H_0$: There are no differences in the maintainability increment of the four states.

$H_A$: Maintainability increment is different in the four states.

Test statistic: F-ratio

Table 5.8 One-Way ANOVA For The Maintainability Increment Results Of Table 4.10

| Source | Sum of Squares | Degree of Freedom (d.f) | Mean-Square | F-ratio | $F_{0.95}$ |
|---|---|---|---|---|---|
| Block | (SSB) 0.00 | 3 | 0.00 | 0.00 | 3.10 |
| Residual | (SSE) 0.22 | 20 | 0.01 | | |
| Total | (SS) 0.22 | 23 | | | |

From Table 5.8, $F_{\text{-ratio}} < F_{0.95}$ (0 < 3.10).

Accept $H_o$

Conclusion: There are no differences in the maintainability increment results of the four states.

## 5.4 AVAILABILITY

### 5.4.1 Testing Whether Availability Is The Same In The Four States

The problem was resolved through a test of hypothesis involving a one-way analysis of variance of Table 4.12, as presented below.

$H_o$: Availability is the same in the four states.

$H_A$: Availability is not the same in the four states.

Test Statistic: F-ratio

Table 5.9 One-Way ANOVA For The Availability Results Of Table 4.12

| Source | Sum of Squares | Degree of Freedom (d.f) | Mean-Square | F-ratio | $F_{0.95}$ |
|---|---|---|---|---|---|
| Block | (SSB) 0.00 | 3 | 0.00 | 0.00 | 3.10 |
| Residual | (SSE) 0.12 | 20 | 0.01 | | |
| Total | (SS) 0.12 | 23 | | | |

From Table 5.9, F-ratio < $F_{0.95}$ (0 < 3.10).

Accept $H_o$

Conclusion: Availability is the same in the four states.

This suggests that availability can be predicted with a good degree of confidence, for handpump-equipped boreholes within the crystalline groundwater Proviince of Northern Nigeria.

### 5.4.2 Availability Prediction Over The 20-Year Assumed Design Life Of The Handpump-Equipped Borehole

Availability has been expressed as

$A = P_s + M_\Delta$ .....(*see column 4 of Table 4.11*)

$= P_s + P_f.M$ .....(see column 6 of Table 4.8)

$= P_s + M(1-P_s)$

However from section 5.3.1, maintainability has a constant value estimated at 0.58, hence

$$A = P_s + 0.58(1-P_s) \quad \text{.....Eqn 5.2}$$

Using the predicted values of $P_s$ in Table 5.6, availability can be predicted as shown in Table 5.10 and plotted in Figure 5.3

Table 5.10 Predicted Values Of Availability Over A 20-Year Time Period

| T (Years) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| $P_s$ | 1.00 | 0.90 | 0.80 | 0.71 | 0.64 | 0.58 | 0.52 | 0.46 |
| $0.58(1-P_s)$ | 0.00 | 0.60 | 0.12 | 0.17 | 0.21 | 0.24 | 0.28 | 0.31 |
| $A=P_s+0.58(1-P_s)$ | 1.00 | 0.96 | 0.92 | 0.88 | 0.85 | 0.82 | 0.80 | 0.77 |

| T (Years) | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|
| $P_s$ | 0.41 | 0.37 | 0.33 | 0.30 | 0.27 | 0.24 | 0.21 | 0.19 |
| $0.58(1-P_s)$ | 0.34 | 0.37 | 0.39 | 0.41 | 0.42 | 0.44 | 0.46 | 0.47 |
| $A=P_s+0.58(1-P_s)$ | 0.75 | 0.74 | 0.72 | 0.71 | 0.69 | 0.68 | 0.67 | 0.66 |

| T (Years) | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|
| $P_s$ | 0.17 | 0.15 | 0.14 | 0.12 | 0.11 |
| $0.58(1-P_s)$ | 0.48 | 0.49 | 0.50 | 0.51 | 0.52 |
| $A=P_s+0.58(1-P_s)$ | 0.65 | 0.64 | 0.64 | 0.63 | 0.63 |

Figure 5.4 also shows the interpolation of the predicted availability, maintainability and probability of survival curves; from which it is clear that with time, availability of the handpump-equipped boreholes depends to a large extent, on the maintainability. This agrees with the theoretical postulations of figure 3.2.

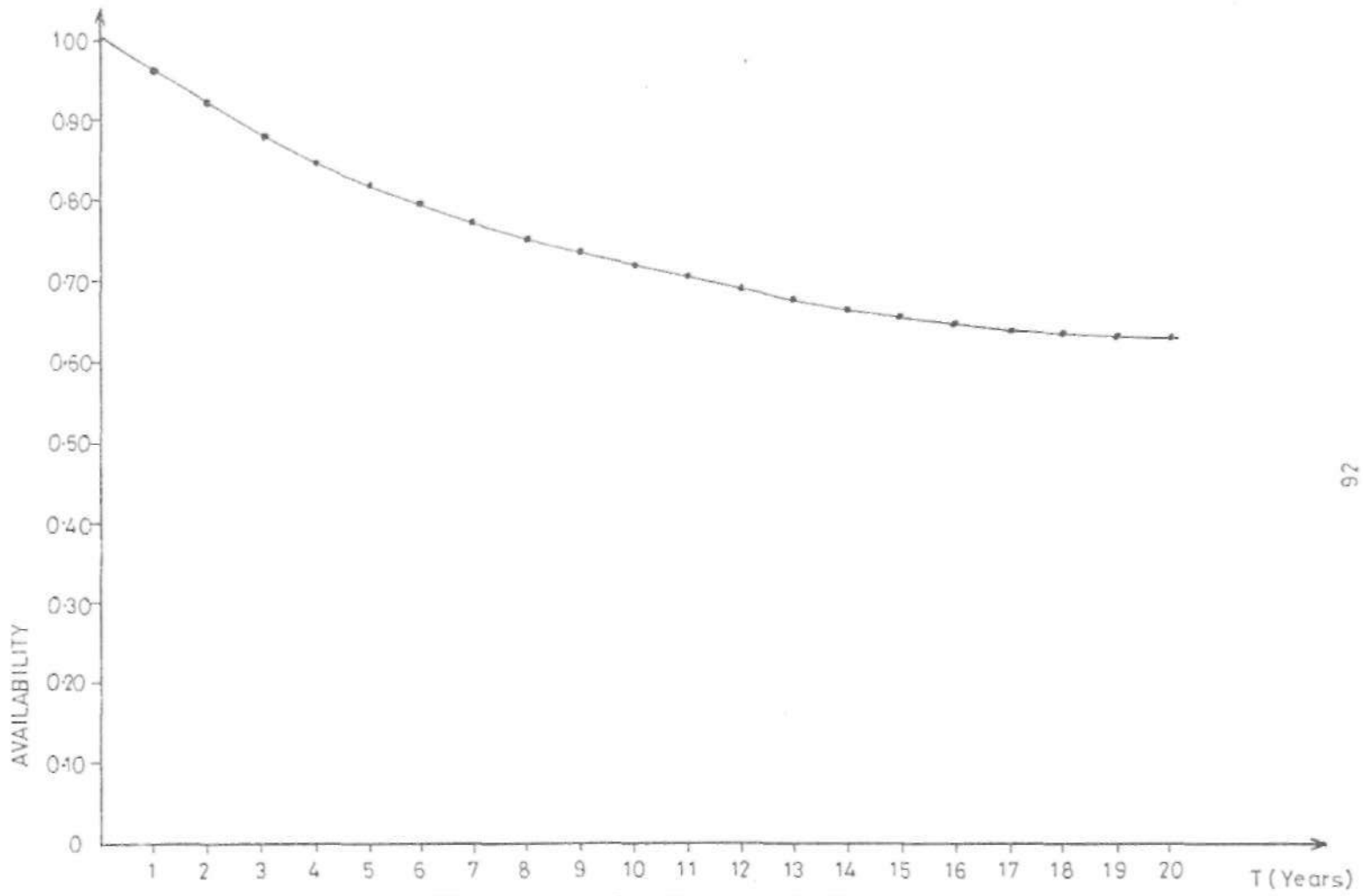



FIG. 5.3 PREDICTED VALUES OF AVAILABILITY OVER A 20-YEAR PERIOD OF TIME

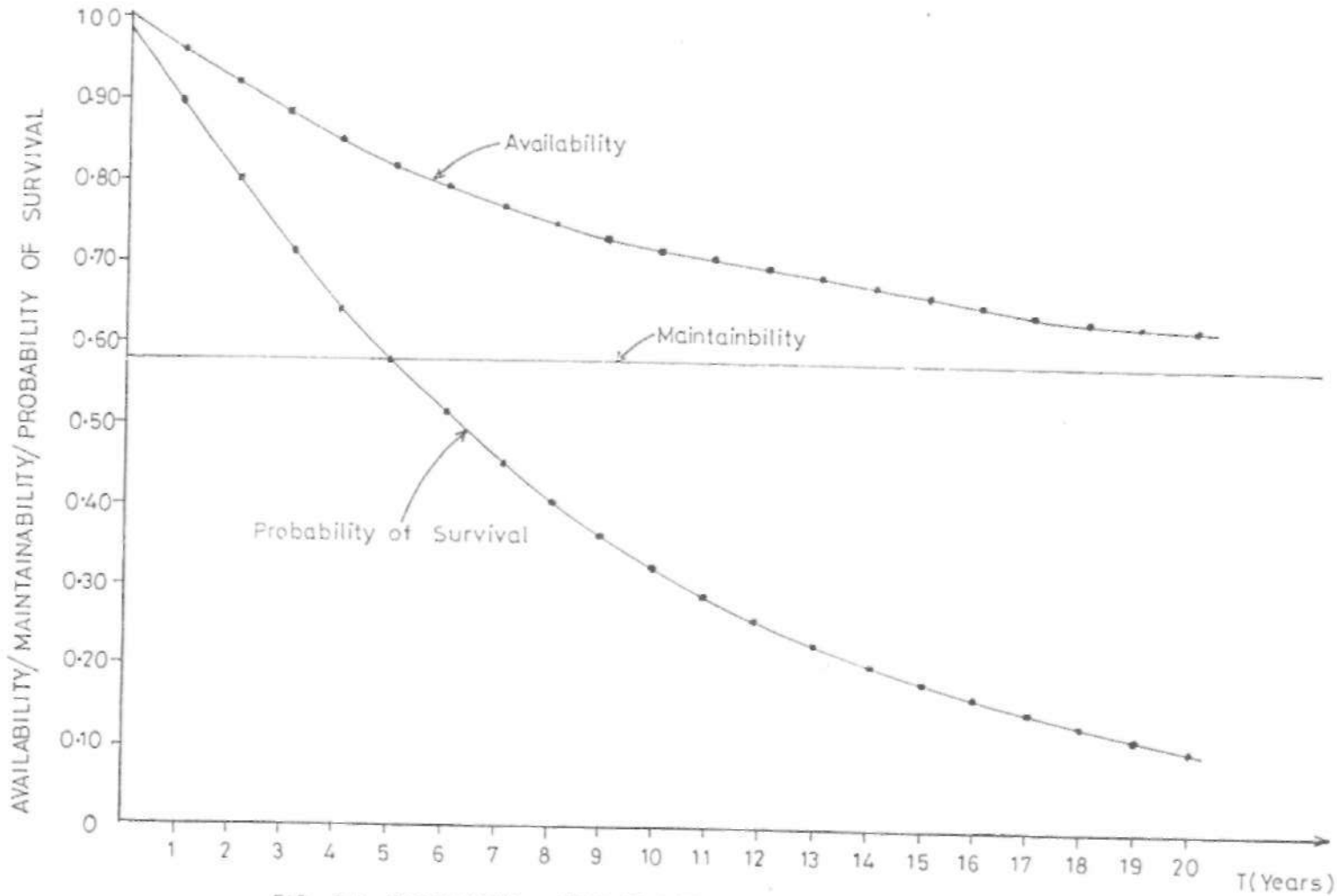



FIG. 5·4 PREDICTED AVAILABILITY, MAINTAINABILITY AND PROBABILITY OF SURVIVAL CURVES

5.5.1 Total Down-Times (Weeks) For The Failed Borehole Units

The basic concern here is whether or not significant differences exist in the recorded values of total down-times in the four states. A one-way analysis of variance of the down-times data of Table 4.3 is used in testing relevant hypothesis on the matter as presented below.

$H_0$: Total down-times are the same in the four states.

$H_A$: Total down-times are different in the four states.

Test statistic: F-ratio

Table 5.11 One-Way ANOVA For The Total Down-Times Results Of Table 4.13.

| Source | Sum of Squares | Degree of Freedom (d.f) | Mean-Square | F.ratio | $F_{0.95}$ |
|---|---|---|---|---|---|
| Block | (SSB) 55.02 | 3 | 18.34 | 1.28 | 3.24 |
| Residual | (SSE) 228.34 | 16 | 14.27 | | |
| Total | (SS) 283.36 | 19 | | | |

From Table 5.11, $F_{\text{-ratio}} < F_{0.95}$ (1.28 < 3.24).

Accept $H_0$

Conclusion: Total down-times are the same in the four states.

5.5.2 Total Repair Times (Hours) For The Failed Borehole Units

A check is made on whether or not siginificant differences exist in the recorded values of total repair-times in the four states. This was examined by means of test similar to the one of section 5.5.1 and utilising the data of Table 4.14.

$H_o$: Total repair-times are the same in the four states.

$H_A$: Total repair-times are different in the four states.

Test statistic: F-ratio

Table 5.12 One-Way ANOVA For The Total Repair-Times Results Of Table 4.14.

| Source | Sum of Squares | Degree of Freedom (d.f) | Mean-Square | F-ratio | $F_{0.95}$ |
|---|---|---|---|---|---|
| Block | (SSB) 8.17 | 3 | 2.72 | 0.12 | 3.24 |
| Residual | (SSE) 349.87 | 16 | 21.87 | | |
| Total | (SS) 358.04 | 19 | | | |

From Table 5.12, F-ratio < $F_{0.95}$ (0.12 < 3.24).

Accept $H_o$

Conclusion: Total repair-times are the same in the four states.

One implication of the conclusions reached in 5.5.1 and 5.5.2 above is that both total down-times and repair-times for failed borehole units in the Crystalline Groundwater Province of Northern Nigeria, can be estimated with a good degree of confidence. These estimates can be obtained from Tables 4.13 and 4.14 respectively by taking the average values of the lower and upper bounds recorded for the four states. Thus the total down-time for each failed borehole is taken as falling between 1.79 and 2.82 weeks while the total repair time lies between 5.03 and 6.75 hours, for 95% of the cases.

## 5.6 UP-TIME RATIOS AND TIME TO FIRST FAILURE

### 5.6.1 Up-Time Ratios for The Failed Borehole Units

The question is whether or not significant diferences exist in the up-time ratios in the four states. A similar procedure to that of 5.5.2 is used to determine the case, using Table 4.15.

$H_0$: Up-time ratios are the same in the four states.

$H_A$: Up-time ratios are different in the four states.

Test statistic: F-ratio

Table 5.13 One-Way ANOVA For The Total Up-Time Ratio Results Of Table 4.15.

| Source | Sum of Squares | Degree of Freedom (d.f) | Mean-Square | F-ratio | $F_{0.95}$ |
|---|---|---|---|---|---|
| Block | (SSB) 1.20 | 3 | 0.40 | 0.001 | 3.24 |
| Residual | (SSE) 12268.11 | 16 | 766.76 | | |
| Total | (SS) 12269.31 | 19 | | | |

From Table 5.13, F-ratio < $F_{0.95}$ (0.12 < 3.24).

Accept $H_0$

Conclusion: Total Up-time ratios are the same in the four states.

The estimated value of the up-time ratio for the area of interest, at 95% confidence interval is between 51.43 and 51.64 weeks per year or 98.90% and 99.31%.

5.6.2 Times To First Failure For The Failed Borehole Units

Again the question here is whether or not the times to first failure are the same in the four states. To determine this a similar procedure to that of section 5.6.1. is adopted.

$H_0$: Times to first failure are the same in the four states.

$H_A$: Times to first failure are different in the four states.

Test statistic: F-ratio

Table 5.14 One-Way ANOVA For The Times To First Failure Results Of Table 4.16.

| Source | Sum of Squares | Degree of Freedom (d.f) | Mean-Square | F-ratio | $F_{0.95}$ |
|---|---|---|---|---|---|
| Block | (SSB) 1105.13 | 3 | 368.28 | 0.11 | 3.24 |
| Residual | (SSE) 51554.62 | 16 | 3222.16 | | |
| Total | (SS) 52659.75 | 19 | | | |

From Table 5.14, F-ratio < $F_{0.95}$ (0.11 < 3.24).

Accept $H_0$

Conclusion: Times to first failure are the same in the four states.

Times to first failure for handpump-equipped boreholes in the crystalline groundwater Province of Northern Nigeria can thus be taken to fall between 98.64 and 133.72 weeks; for 95% of the cases.

## 5.7 SUMMARY OF RESULTS

1. Component, sub-system and system failure patterns of the boreholes are respectively the same in the crystalline groundwater Province of Northern Nigeria.
2. The cylinder assembly, the riser pipe and the head assembly conponents of the handpump sub-systems with about 40%, 22% and 12% of the total system failure repectively, recorded the highest failure frequencies.
3. The handpump sub-system has a higher failure frequency (about 88% of the system failure) than the well.
4. Probability of survival of the boreholes is the same within the area and is an exponential function of time T and constant failure rate r = 0.11.
5. Maintainability of the boreholes is uniform within the area of interest and also constant with respect to time. It is estimated at a value of 0.58.
6. Availability of the boreholes is the same within the province studied and its value with time depends to a large extent on maintainability. From a probability of 1.0 at year zero, the predicted availability drops to 0.82,0.72, 0.66 and 0.63 at years 5, 10, 15 and 20 respectively.
7. Total down-times are the same in the province and have estimated values in the range of 1.79 and 2.82 weeks, at 95% confidence interval, for the five-year period studied.
8. Total repair times are the same in the province and has an estimated values in the range of 5.03 and 6.75 hours at

95% confidence interval, for the five-year period studied.

9. Up-time ratios are the same in the province, with 95% confidence interval estimate of between 51.43 and 51.64 weeks per year or 98.90% and 99.31%.

10. Times to first failure are the same in the province, with a 95% confidence interval estimate of between 98.64 and 133.72 weeks.

## 5.8 DISCUSSION

### 5.8.1 Reliability Of The Field Investigation Data

The reliability of the data from the field investigation of this work depends largely on the accuracy of the records kept on the installed boreholes by the various agencies studied. Deficiencies in these records are however not uncommon. This is mainly due to the fact that the purpose of the agencies in accumulating the records is not specifically for reliability and maintainability evaluation but rather for a general account of the life cycle of the installations. These deficiencies are usually in the form of omission or careless recording of some necessary information such as:

i) The exact time of system failure, commencement of repair and completion of repair work.

ii) Inadequate description of nature and causes of failure.

ii) Inadequate description of repair work carried out.

However efforts were made in the process of completing the questionnaires to extract or estimate some of the necessary data. An approach for generating a more reliable data for borehole availaibaility studies is given in section 6.2.2.

### 5.8.2 The Constant Failure Rate

A constant failure rate was established in section 5.2.2 for the boreholes over their first five years of operation and was used in section 5.2.3 for predicting the probability of survival of the boreholes over their designed life span The constant failure rate implies that chance alone dictates when a failure occurs and that the age of the boreholes does not affect the issue - Chatfield (1975 p.323), Ibe and Wein (1992 pp. 92-96). This is not surprising for well developed components within their designed life span. Outside this period however, age will most likely affect the failure rate and the exponential model will no longer be valid. Other models such as the Weilbull model - Barlow and Proschan (1965), Chatfield (1975, pp 323-326), Chen and Shaw (1993, pp 566-571) - which successfully describe fatigue failure could be employed in such situations.

### 5.8.3 Availability Result

The different results obtained in this work from the two availability models used should not be confusing as they account for different measures or definitions of availability. The exponential model measures the probability that the boreholes will give adequate performance within five years, with no down-time exceeding one week. The result was presented in Table 4.12 and the projected values over a period of twenty years were given in Table 5.10. A comparison of these results with the availability standards of section 3.5.3 portrays the need for improvement of the availability of the boreholes. It may be recalled that standards stipulate availability factors not less

than 0.85 and 0.98, for normal and operationally vital systems respectively. The field results show a drop of below 0.85 as from the fourth year while the projected values depict further drops to 0.82, 0.72, 0.66 and 0.63 in the 5th, 10th, 15th and 20th years respectively.

The up-time ratio model measures the percentage of time over the initial five-year period of operation for which the boreholes are expected to be in operable state. The result gives values (at 95% confidence interval estimation), in the range of 98.90% and 99.31%. These values satisfy the availability standards, even at the level of operationally vital systems. This not-withstanding, a comparison of the total down-times for the boreholes (with values in the range of 1.79 and 2.82 weeks) and the total repair times (which lies between 5.03 and 6.75 hours), suggests room for improvement of the up-time ratio results. This is evident from the fact that a greater part of the down-times is accounted for by either, or both of late reporting of failures and slow rate of mobilising resources for the repair.

### 5.8.4 Criteria For Improving The Availability Of The Handpump-Equipped Boreholes

Availability can be improved by improving either, or both of probability of survival and maintainability.

For the probability of survival, equation 3.4 shows that for a given time period T, it is dependent only on failure rate r; and will increase as r decreases. Thus probability of survival can be increased by lowering failure rate This can be practically achieved in a number of ways which include:

i) Improving the inherent reliability of components and parts of the system.

ii) Compliance to standard practice at the design and construction stages in borehole projects. The steps listed in section 2.1.2 can serve as a good guide for achieving this.

On maintainability, equation 3.8 shows that for a given maintenance time constraint t; maintainability is dependent only on the maintenance action rate u. But maintenance action rate is dependent on time taken for: failure identification and reporting, mobilising resources for maintenance, and effecting the repair. Also as stated earlier in section 5.8.3, time taken for failure identification as well as that for mobilising resources for maintenance, account for over 99% of the total down-times of failed boreholes. Maintenance action rate and hence maitainability of handpump-equipped boreholes can therefore be substantially improved by decreasing the time spent on failure identification and reporting, and the time for mobilising resources for maintenance work.

# CHAPTER SIX

## CONCLUSIONS AND RECOMMENDATIONS

### 6.1 CONCLUSION

Availability as a measure of the up-time of handpump-equipped boreholes in the Crystalline Groundwater Province of Northern Nigeria, over the initial five-year period of operation is considered satisfactory; given its average value which is higher than the 0.98 factor stipulated for the highest standard of system operation - operationally vital systems.

As a measure of the probability for adequate performance over the designed life span of the boreholes, with no down-time in excess of one week, availability is problematic. The problem which begins to manifest from the fourth year of operation (when the availability factor drops below the 0.85 minimum standard stipulated for normal operational-level systems), deepens in the subsequent years and reaches an estimated lowest level of 0.63 in the last year of the twenty-year designed life assumed for the boreholes. The two principal factors in availability - reliability and maintainability - are found to have effects on the problem. High handpump failure frequency (88% approx.of the system failure) accounts for the greater portion of the reliability problems, while late identification and reporting of failures are the major problems in the maintainability.

The task of ensuring adequate availability over the designed life span of the boreholes is therefore that which would demand diligent compliance to the highest of standards in design, construction and operational/maintenance phases of borehole projects. Throughout these phases, emphasis must be on the

factors which enhance reliability and maintainability. Proper geophysical investigation, selection of good casing and screen for the well and choice of handpump with proven reliability must be pursued at the design phase. The construction stage must ensure good borehole sinking method with careful sampling and recording of ground conditions, proper borehole alignment, installation of casings, screens and pumps, and adequate well-development for yield optimisation. Lastly, prompt failure identification and reporting as well as quick mobilisation of resources for maintenance and repair works; must be the emphasis at the operational/maintenance phase.

## 6.2 RECOMMENDATIONS

### 6.2.1 Suggestions For Improving the Availability Of The Boreholes

a. The inherent reliability of the handpump sub-system should be improved. This could be pursued in either or both of two ways:

i) Improving the reliability of the cylinder assembly, riser pipe and head assembly components, which together account for about 85% of the handpump and 75% of the total system failures.

ii) The system should be designed and installed with double handpumps. The advantage is that if one pump fails, the other one takes over the the operation and if the failed pump is repaired before the other one could fail, then the availability is not affected by the failure. The major disadvantage however is the increased capital

cost due to increased number of pumps, as well as larger well diameters which implies increased drilling, casing and screening costs. Wells installed with double India Mark II handpumps are however already in use in Senegal,Cambodia and Uganda - Waterfront (1993 p.10).

b. The maintainability of the system should be improved. The field data shows that on the average, only about 56% of failed borehole units are restored to operational effectiveness within the maintenance time constraint of one week. This situation should be improved by re-organisation of the maintenance process to ensure the following:

i) Closer monitoring of the systems in operation to ensure prompt failure identification and reporting.

ii) Maintenance of good and readily accessible stock of spares. The data supplied in this work on component failure frequencies will be useful for inventory control and judicious use of resources in this connection.

iii) Swift mobilisation of resources for repair works.

In addition to these, the skills of the maintenance operatives should be enhanced by regular training programmes and workshops.

### 6.2.2 Suggestions For Obtaining Reliable Field Data For Borehole Availability Evaluation

For more reliable data, organisations such as the UNICEF, and the various Water Authorities in countries which engaged in installation of large numbers of handpump-equipped boreholes, should create properly trained and well equipped Monitoring Units to generate operational reliability and maintainability data over longer periods of say ten to twenty years of initial operation of the boreholes. A computer filing system is recommended for this purpose and a check list of information to be kept is recommended in Table 6.1.

Table 6.1 Check List Of Necessary Reliability And Maintainability Information

a. Basic Data

- i) Date of installation/comissioning
- ii) Designed life
- iii) Estimated number of people to be served
- iv) Location and brief topographical description

b. System Description

- i) Well
  - Casing description
  - Screen description
- ii) Handpump
  - Type
  - List and brief description of components

c. System Performance Record

i) Routine maintenance record

- Date, time and duration of maintenance
- Description of work done

ii) Failure and Repair records

- Failure number; 1st, 2nd, 3rd etc.
- Date and time of failure
- Failure description, nature and causes
- Date and time of commencement of repair
- Duration of repair
- Description of repair work done.

### 6.2.3 Areas of Further Research

Availability of handpump-equipped boreholes in the ten other groundwater provinces of Nigeria should be studied. The operational reliability of the other types of handpump [e.g. the Tarra pump and Afridev which are also gaining ground in Nigeria] should also be assessed.

## REFERENCES


1) Anonymous (1995) Brief On The Kwara State UNICEF-assisted Water And Sanitation Project 1984-1995. UNICEF WATSAN Office Ilorin.

2) Arlosorof S; Ernest W.R. and Hofkes E.H (1987) Community Water Supply The Handpump Option. United Nations Development Programme and World Bank's Contribution to the International Drinking Water Supply and Sanitation Decade.

3) Atlas of the Federal Republic of Nigeria, First Edition.

4) Barlow R.E and Hunter L.C. (1960), Mathematical Models for System's Reliability. The Sylvania Technologist Vol. 13 January.

5) Barry R. (1976), The Construction of Buildings Vol. 5, Granada Publishing Limited London.

6) Blanchard B.S. (1991) System Engineering Management John Wiley & Sons Inc. New York.

7) Boulton N.S. and pontin J.M.A (1971). An Extended Theory of Delayed Yield From Storage Applied to Pumping Tests in Unconfined Aquifers. Hydrology Vol. 14 No 1.

8) Calabro S.R. (1962) Reliability Principles and Practices. Mcgraw Hill Book Company, New York.

9) Chan J.K. and Shaw L. (1993) Modelling Repairable Systems With Failure Rates That Depend On age And Maintenace. IEE Transactions On Reliability Vol 42 No 4, December.

10) Chatfield C. (1975) Statistics For Technology. Halsted Press, a Division of John Wiley & Sons, Inc. New York.

11) de Rooy C. Akpnmkpuk E.S; Ezeoke F.L; Udokang S.U. and Umanah S.P. (1986) Mechanised Or Handpump-Equipped

Boreholes? Which is the Most Adequate For The Rural Areas of Nigeria? "First Annual Symposium and Training Workshop On Groundwater Resources in Nigeria", Lagos, Nigeria, 23rd-25th July.

12) de Rooy C and Olokun A. (1986). The Hydrogeological and Cost Feasibility Of Shallow Handpump-Equipped Borewells in Rural Areas of Nigeria. "First Annual Symposium and Training Workshop On Groundwater Resources in Nigeria", Lagos, Nigeria, 23rd-25th July.

13) Donaldson L.D. and Karim M. (1988). A Village Level Operation & Maintenance (VLOM) System for WATSAN Project Handpump-Equipped Boreholes in Nigeria. UNICEF-Nigeria, December.

14) Driscoll F.G. (1989) Groundwater and Wells 2nd Ed. Johnson Filteration Systems Inc. St Paul, Minnesotta 55112.

15) Fraenkel P.C (Ed) (1986) The Water Lifting Devices FAO Irrigation Paper 43.

16) Frankel R.J. (1975) Systems Evaluation of Village Water Supply and Treatment in Thailand. Water Resources Research Vol. 11, No 3.

17) Goulden E.C. (1990) An Analytic Approach To Performing a Maintainability Demonstration IEEE Transaction on Reliability Vol. 39, No 1.

18) Haith D.A. (1982) Environmental Systems Optimisation. John Wiley & Sons Inc. USA.

19) Hofkes E.H. (Ed) (1981). Small Community Water Supplies International Reference Centre for Community Water Supply

and Sanitation, Netherlands.

20) Huiseman L. (1972) Groundwater Recovery MacMillan New York.

21) Ibe O.C. and Wein A.S (1992). Availability of Systems With Partially Observable Failure. IEEE Transaction on Reliability Vol. 41, No 1. March.

22) Lazanyi I. (1985). Report of Committee for Groundwater Monitoring and Inbalance in Kano State.

23) Okun D.A. and Ernest W.R. (1987) Community Piped Water Supply Systems in Developing Countries. The World Bank washington D.C.

24) Rau J.G. (1970) Optimization and Probability In Systems Engineering. Van Nostrand Reinhold Coy, New York.

25) Robertson J.A. (1969). On The Planned Maintenance Of Buildings and Structres. In: Proceedings of Institute of Civil Engineers, London.

26) Sahni B.M (1981) Evaluating Groundwater Supply in New Project Areas With Special Reference to Developing Countries. Water Supply & Management Vol. 5.

27) Sahni B.M and Seth H.S (1979). Storage Coefficient From Grounwater Maps. In: Proceedings of American Society of Civil Engineers 105 (IR2).

28) Soliman M.M. (1972) Determination of Hydrological Factors With a Well Recorder, In: Proceedings of 2nd International Symposium in Hydrology Port Collins, Columbia.

29) Stephens R.t. (1979) Operational Test & Evaluation A Systems Engineering Process. John Wiley & Sons New York

30) Strestova T.D (1972) Unsteady Radial Flow in an Unconfined Aquifer. Water Resources Reserve Vol. 8 No 4.

31) UNICEF and Federal Ministry of Health (1986) Rural Water and Sanitation Programme - Project Implementation (First Draft), Lagos, Nigeria.

32) Walton W.C. (1960) Groundwater Resources Evaluation McGraw Hill Book Company New York.

33) WATERfront (1993), Water Supply, Environmental Sanitation and Hygiene news, UNICEF (WES Section) Issue 4, August, New York.

34) Waterhouse J. (1982) Water Engineering For Agriculture Bastford Academic and Education Ltd.

35) WHO (1983), Minimum Evaluation Procedure - M.E.P. - for Water Supply and Sanitation Projects Document ETS/83.1

36) World Bank and Federal Republic of Nigeria (1986). Federal Republic of Nigeria Rural Water Supply and Sanitation Sector Memorandum, (working level draft for discussion), Report No 6203-UNI, Washington DC.

APPENDIX A

AVAILABILITY OPTIMIZATION OF EXISTING WATER SUPPLY SYSTEMS FOR RURAL COMMUNITIES IN NORTHERN NIGERIA

QUESTIONNAIRE

Please kindly respond to the questions here in listed, supplying to accurately as possible the information requested. The work is a Ph.D research and the information given will be treated confidentially and for academic purposes only.

PART A

1. GENERAL INFORMATION

(a) Name of Village or Organisation ..... UNICEF (KWARA STATE)
.....

(b) Total number of installed Boreholes.....634.....

(c) Number currently in Operation.....489.....

2. TIME CONSTRAINT FOR MAINTENANCE WORK

(a) From the view point of users' convinience only, what would you consider the maximum tolerable down time for a borehole system serving a rural community (Please tick as appropriate).

- upto one week ✓
- 1 to 2 weeks
- 2 to 3 weeks
- 3 to 4 weeks
- 4 to 5 weeks

(b) From the view point of technical and logistic problems involved in the maintenance of borehole systems (time for identifying and reporting failure, resource mobilisation time, and time spent on actual repair/maintenance work), what would you consider:

i) The minimum time needed for effective restoration of a failed system.

- 1 to 2 weeks ✓
- 2 to 3 weeks
- 3 to 4 weeks
- 4 to 5 weeks
- 5 to 6 weeks
- above 6 weeks (Please state the exact period.....)

ii) The minimum shut down time for routine maintenance

- upto 1 week ✓
- 1 to 2 weeks
- 2 to 3 weeks
- 3 to 4 weeks
- 4 to 5 weeks
- 5 to 6 weeks
- above 6 weeks (please state the exact period.....)

2. Borehold System Availability Improvement

(a) Freely suggest under the headings below, measures that would improve the use readiness and fitness (availability) of boarehole systems:

(i) Design:.....

.....

.....

.....

(ii) Installation .....

.....

.....

.....

(iii) Maintenance System .....

.....

.....

APPENDIX B (38) KUGIJI (WAJIRE) KAIMA LGA

FORM 1

1. INDIVIDUAL BOREHOLE SYSTEM DESCRIPTION & PERFORMANCE RECORD (Please use one of Form B for each borehole)

(a) Basic Data

i) Date of Installation/Commissioning: 7-12-91

ii) Design Life: 50 yrs.

iii) Estimated number of people served: 350

iv) Estimated rate of us - piople per hour: 15

or Litres per hour: 75

v) Location (Brief torpographical description): Kugiji (Wajire) Kaima LG

(b) System Description

The borehole system components are listed in i - vi below. A system may not include all the components, so please tick against the components present in the borehole under consideration.
As an example, a borehole with concrete casing shall be ticked thus:

Borehole Casing — Concrete

Steel

NOW PLEASE TICK AS APPROPRIATE

i) Borehole

. Casing — P.V.C ✓ Concrete Steel

. Screen — Galvanised Steel; Stainless steel; Any other type (indicate): uPVC

. Depth (metres): 40 m

. Yield: 3.1 Lts/Sec

ii) Water Lifting Device/pump

. Simple Hand Pump — Indian Mark II; Indian Mark III ✓; A Fridev; Any other (please name):

. Motorized
- Submersible
- Motor assessible above ground

iii) Boosting Pump
- Duplicate flow activated pumps
- Any other type (please describe
.....
.....

iv) Storage Tank

. Underground
- Contrete
- Steel

. Overhead
- Concrete
- Steel

v) System Pipe Work
- Cast Iron
- Galvanised Steel
- Other type (please name it):. G.I pipes
.....
.....

System Distribution Pipe Work

Distribution Pipe Work
- Cast Iron
- Galvanised Steel
- Other type (please give the name):.....
.....

(c) System Performance Record

(i) Failure Records

| Failures | Date | Nature of failure (eg. clogged screen dried up will, pump failure etc.) | Date of Commencement of repair | Description of Repair/Maintenance work done | Duration of repair |
|---|---|---|---|---|---|
| 1st Failure | 6/7/92 | Pump failure (Worn out leather cups) | 9/7/92 | Replacement of leather cups | 2 hrs |
| 2nd failure | 7/11/92 | Broken pipe | 8/11/92 | Replacement of 10' long G.I pipe | 1 hr |
| 3rd failure | | | | | |
| 54th failure | | | | | |
| 5th failure | | | | | |
| 6th failure | | | | | |
| 7th failure | | | | | |
| 8th failure | | | | | |

If there are more than 8 failures, please use the backside of this page or attach

Appendix C  Sample of Initial Collation of Failure Data From Questionnaires

| Borehole Number | Failure Number | Sub-System | Component | Failure Description | Description of Repair Work |
|---|---|---|---|---|---|
| 1 | 1 | Pump | Riser Pipe | Breakage | Broken pipe changed from galvanised iron to stainless steel pipe. Pump pulled out, serviced and broken rod replaced. |
| | 2 | Pump | Connecting Rod | Breakage | |
| 2 | 1 | Pump | Riser Pipe | Corrosion | Pump pulled out and serviced. Pump depth increased by adding one lenght of riser of riser pipe and connecting rod. |
| | 2 | Well | Water | High drop down at dy season | |
| 3 | 1 | Well | Casing | Caving from 112 to 87ft. Dirty water produced as a result. | Reflushing and reinstallation. |
| 4 | 1 | Pump | Head Assembly and cylinder | Stiff handle shaft and clogged cylinder | Pump pulled out and serviced. Two ball bearings at the handle replaced. |
| | 2 | Well | Water | High drop down at dry season | Pump depth increased by adding one lenght of riser pipe and connecting rod. |
| 5 | 1 | Well | Water | Water discolouration. | Pump pulled out, thoroughly washed, serviced and reinstalled. |
| | 2 | Well | Water/Platform | Platform discolouration and low yield. | Well head cleaned and pump depth increased. |

| Borehole Number | Failure Number | Sub-System | Component | Failure Description | Description of Repair work |
|---|---|---|---|---|---|
| 6 | 1<br>2 | Pump<br>Pump | Riser pipe<br>Connecting rod and Riser pipe | Breakage<br>Three lenght of riser pipe with rods broken and lost into the well. | Riser pipe changed.<br>Pipes and rods collected and new pump installed. |
| 7 | 1 | Well and pump | Water and Water Tank | Particles in water. Rusty water tank. | Pump's water tank replaced. Well cleaned and screen replaced. |
| 8 | 1<br>2 | Pump<br>Pump | Head Assembly<br>Cylinder/Riser pipe | Chain cut.<br>Upper valve disconnection/corrosion of riser pipe. | Chain replaced.<br>Valve replaced. Pipe serviced. |
| 9 | 1 | Pump | Head Assembly | Broken head bearing axle and handle. | Bearing replaced and handle wielded. |
| 10 | 1<br>2 | Pump<br>Pump | Cylinder<br>- | Worn out sealing ring and cup washer.<br>Routine check. | Sealing ring and cupwasher replaced; pump serviced.<br>General servicing. |
| 11 | 1<br>2 | Pump<br>Pump | Cylinder<br>Water tank | Valve worn out.<br>Rusty and broken water tank. | Valve replaced.<br>Water tank replaced. |
| 12 | 1<br>2 | Pump<br>Pump | Head Assembly<br>Connecting rod | Stiff handle, very difficult to operate.<br>Rod disconnection. | Pump head replaced.<br>Rod repaired and pump serviced. |

Example of Initial Collation of Failure Data from Questionnaires

| Borehole Number | Failure Number | Sub-System | Component | Failure Description | Description of Repair Work |
|---|---|---|---|---|---|
| 1 | 1 | Pump | Riser Pipe | Broken pipe changed from galvanised iron to stainless steel pipe. Pump pulled out, serviced and broken rod replaced. | |
| | 2 | Pump | Connecting Rod | Breakage | |
| 2 | 1 | Pump | Riser Pipe | Corrosion | Pump pulled out and serviced, |
| | 2 | Well | Water | High drop down at dry season | Pump depth increased by adding one length of riser pipe and connecting rod. |
| 3 | 1 | Well | Casing | Caving from lit to silt. Dirty water produced as a result. | Reflushing and reinstallation. |
| 4 | 1 | Pump | Head Assembly and cylinder | Shift handle shaft and clogged cylinder | Pump pulled out and serviced. Two ball bearings at the handle replaced. |
| | 2 | Well | Water | High drop down at dry season | Pump depth increased by adding one length of riser pipe and connecting rod. |
| 5 | 1 | Well | Water | Water dissolouration. | Pump pulled out, thoroughly washed, serviced and |
| | 2 | Well | Water/Platform | Plastform dissolouration and low yield. | reinstalled. Well head cleansed and pump depth increased. |

| Borehole Number | Failure Number | Sub-System | Component | Failure Description | Description of Repair work |
|---|---|---|---|---|---|
| 6 | 1<br>2 | Pump<br>Pump | Riser pipe<br>Connecting rod and Riser pipe | Breakage<br>Three lenght of riser pipe with rods broken and lost into the well. | Riser pipe changed.<br>Pipes and rods collected and new pump installed. |
| 7 | 1 | Well and pump | Water and Water Tank | Particles in water. Rusty water tank. | Pump's water tank replaced. Well cleaned and screen replaced. |
| 8 | 1<br>2 | Pump<br>Pump | Head Assembly<br>Cylinder/Riser pipe | Chain cut.<br>Upper valve disconnection/corrosion of riser pipe. | Chain replaced.<br>Valve replaced. Pipe serviced. |
| 9 | 1 | Pump | Head Assembly | Broken head bearing axle and handle. | Bearing replaced and handle wielded. |
| 10 | 1<br>2 | Pump<br>Pump | Cylinder<br>- | Worn out sealing ring and cup washer.<br>Routine check. | Sealing ring and cupwasher replaced; pump serviced.<br>General servicing. |
| 11 | 1<br>2 | Pump<br>Pump | Cylinder<br>Water tank | Valve worn out.<br>Rusty and broken water tank. | Valve replaced.<br>Water tank replaced. |
| 12 | 1<br>2 | Pump<br>Pump | Head Assembly<br>Connecting rod | Stiff handle, very difficult to operate.<br>Rod disconnection. | Pump head replaced.<br>Rod repaired and pump serviced. |

| Borehole Number | Failure Number | Sub-System | Component | Failure Description | Description of Repair Work |
|---|---|---|---|---|---|
| 13 | 1 | Pump | Cylinder | Loose valve and worn rubber seat. | Loose valve tightened and worn out seat replaced. |
| 14 | 1 | Pump | Cylinder | Loosened plunger rod and coupler. | Coupler replaced and pump serviced. |
| 15 | 1 | Pump | Connecting rod | Coupling thread damaged at a depth of 15m. | Retreading and replacement of coupler. |
| 16 | 1 | Pump | Water tank | Broken pipe | Water tank wielded. |
| 17 | 1 | Pump | Cylinder | Weak water flow due to worn out cupwasher. | Cupwasher replaced and pump serviced. |
| 18 | 1 | Pump | Cylinder | Broken plunger rod. | Rod replaced and pump serviced. |
| 19 | 1 | Pump/Well | Cylinder/Well casing and screen | Caving of well, gravels penetrate screen into pump cylinder. | Pump pulled out, well depth reduced from 30 to 24 metres and pump serviced. |
| 20 | 1 | Pump | Head Assembly | Jerking handle. | Handle repaired and pump serviced. |
| 21 | 1 | Well | Water | Water odour and discolouration. | Well reflushing and replacement of the pump's galvanised iron riser pipe with stainless steel pipes. |
| 22 | 1 | Pump | Riser pipe | Leakage at metre depth. | Leaking pipe welded and pump serviced. |

| Borehole Number | Failure Number | Sub-System | Component | Failure Description | Description of Repair Work |
|---|---|---|---|---|---|
| 23 | 1 | Pump | Cylinder | Broken plunger rod and worn cut cup washer. | Rod and washer replaced. |
| 24 | 1 | Pump | Riser pipe | Perforation of sections of the pipe. Discoloured water produced. | Bad Section of pipe replaced; pump serviced. |
| 25 | 1 | Pump | Riser pipe | Disconnected and perforated at 30 metre depth. | Reconnection and replacemnt of bad pipe section. |
| 26 | 1 | Pump | Head Assembly | Chain cut and stiff handle shaft. | Replacement of chain and bearing. |
| 27 | 1 | Pump | Cylinder | Plunger rod coupler loosened. | Coupler replaced. |
| | 2 | Pump | Cylinder | Upper valve malfunction. | Valve guide and upper valve replaced. |
| 28 | 1 | Pump | Cylinder | Broken plunger and push rods. | Plunger and push rods replaced. |
| 29 | 1 | Pump | Cylinder | Worn out washer; damaged sealing ring. | Washer and sealing ring replaced. |
| 30 | 1 | Pump | Cylinder | Worn out washer; damaged sealing ring. | Washer and sealing ring replaced. |
| 31 | 1 | Pump | Cylinder | Valve failure. | Valve replaced. |
| | 2 | Pump | Cylinder | Worn out washers. | Washers replaced. |
| | 3 | Pump | Riser pipe | Breakage. | Broken pipe sections replaced. |

| Borehole Number | Failure Number | Sub-System | Component | Failure Description | Description of Repair Work |
|---|---|---|---|---|---|
| 32 | 1 | Pump | Cylinder | Worn out rubber seating. | Rubber seating replaced. |
| | 2 | Pump | Cylinder | Valve failure. | Valve replaced. |
| | 3 | Pump | Cylinder | Worn out washer. | Washer replaced. |
| | 4 | Pump | Riser pipe | Breakage. | Two lenghts of pipe replaced. |
| 33 | 1 | Pump | Riser pipe | Breakage. | Broken pipe replaced. |
| | 2 | Pump | Cylinder | Weak rubber seating. | Rubber seating replaced. |
| 34 | 1 | Pump | Cylinder and Head Assembly | Cylinder failure and broken handle. | Cylinder and handle replaced. |
| 35 | 1 | Pump | Cylinder | Worn out rubber seating. | Rubber seatings replaced. |
| | 2 | Pump | Riser pipe | Breakage. | One lenght of pipe replaced. |
| 36 | 1 | Pump | Riser pipe | Rust pipe. | Pipe replaced. |
| | 2 | Pump | Cylinder | Worn out rubber seating. | Seatings replaced. |
| 37 | 1 | Pump | Head assembly | Broken handle. | Handle replaced. |
| | 2 | Pump | Riser pipe | Rust pipe. | One lenght of pipe replaced. |
| 38 | 1 | Pump | Cylinder | Valve failure. | Valve replaced. |
| | 2 | Pump | Cylinder | Worn out rubber seating. | Seatings replaced. |
| 39 | 1 | Pump | Riser pipe | Rust pipe. | Pipe replaced. |
| | 2 | Pump | Cylinder | Worn out rubber seating. | Seatings replaced. |

| Borehole Number | Failure Number | Sub-System | Component | Failure Description | Description of Repair Work |
|---|---|---|---|---|---|
| 40 | 1 | Pump | Riser pipe | Perforated pipe sections. | Two lenghts of pipe replaced. |
| | 2 | Pump | Riser pipe | Rust pipe | Affected pipe sections replaced. |
| 41 | 1 | Pump | Cylinder | Weak rubber seatings. | Seatings replaced. |
| | 2 | Pump | Riser pipe and Connecting rod | Rust pipe and rod. | Pipe and rod replaced. |
| 42 | 1 | Pump | Riser pipe and Connecting rod | Rust pipe and rod. | Pipe and rod replaced. |
| | 2 | Pump | Cylinder | Valve failure. | Valve replaced. |
| | 3 | Pump | Head Assembly | Loose handle. | Handle replaced. |
| 43 | 1 | Pump | Riser pipe | Rust pipe. | Affected pipes replaced. |
| | 2 | Pump | Cylinder | Weak rubber seatings. | Rubber seatings replaced. |
| | 3 | Pump | Cylinder | Weak rubber seatings. | Rubber seatings replaced. |
| 44 | 1 | Pump | Riser pipe and connecting rod | Rust pipe and rod. | Pipe and rod replaced. |
| | 2 | Pump | Cylinder | Valve failure. | Valves replaced. |
| | 3 | Pump | Riser pipe | Breakage. | Affected pipe sections replaced. |
| | 4 | Pump | Head Assembly | Chain cut and broken chain bearing. | Chain and bearing replaced. |
| 45 | 1 | Pump | Cylinder | Weak rubber seatings. | Seatings replaced. |
| | 2 | Pump | Riser pipe | Holes in pipe. | Affected pipe sections replaced. |
| | 3 | Pump | Cylinder | Weak rubber seatings. | Seatings replaced. |

| Borehole Number | Failure Number | Sub-System | Component | Failure Description | Description of Repair Work |
|---|---|---|---|---|---|
| 46 | 1 | Pump | Cylinder | Valve failure. Weak rubber seatings. | Valve replaced. Seatings replaced. |
| | 2 | Pump | Cylinder | | |
| 47 | 1 | Pump | Cylinder | Weak rubber seatings. | Seatings replaced. |
| | | | Head Assembly | Loose handle. | Handle replaced. |
| | 2 | Pump | Cylinder | Valve failure. | Valve replaced. |
| | 3 | Pump | Cylinder | Weak rubber seatings. | Seatings replaced. |
| 49 | 1 | Pump | Cylinder | Valve failure. | Valve replaced. |
| | | | Riser pipe | Breakage. | Pipe replaced. |
| | 2 | Pump | | | |
| | 3 | Pump | | | |

Appendix D PROCEDURE FOR THE ANALYSIS OF VARIANCE

## 1.0 Notations

$X_{ij}$ = The observation in the ith row and jth column

$T_i$ = Sum of the ith row

$T_j$ = Sum of the jth column

T = The grand total

$X_i$ = Mean of the ith row

$X_j$ = Mean of the jth column

X = Grand mean

n = Nukmber of rows

k = Number of columns

C = Correction factor

## 2.0 Definitions

i. Total sum of squares (SS)

$$SS = \sum_{i=1}^{n} \sum_{j=1}^{k} (X_{ij} - \overline{X})$$

$$= \sum_{i} \sum_{j} X^{2}{}_{ij} - \frac{T^2}{Kn}$$

ii. Sum of squares for errors (SSE)

$$(SSE) = \sum_{i=1}^{n} \sum_{j=1}^{k} (X_{ij} - \overline{X}_j)^2$$

$$(SSE) = \sum_{i}^{n} \sum_{j=1}^{k} X^{2}{}_{ij} - (\sum_{j=1}^{k} T^{2}{}_{j})/n$$

iii. Sum of squares treatment (SST)

$$(SST) = \sum_{i=1}^{n}\sum_{j=1}^{k} (\overline{X}_j - \overline{X})^2$$

$$= \sum_{j} (T^2{}_j)/n - \frac{T^2}{Kn}$$

iv. Sum of squares between blocks (SSB)

$$(SSB) = K\sum_{i=1}^{n} (\overline{X}_i - \overline{X})^2$$

$$= \sum_{i=1}^{n} (T^2{}_i)/K - \frac{T^2}{KN}$$

$$(SSB) = K\sum_{i=1}^{n} (\overline{X}_i - \overline{X})^2$$

v. Degree of freedom associated with SST = (K-1)

vi. Degree of freedom associated with SSB = (n-1)

vii. Degree of freedom associated with SS = (Kn-1)

3.0 Procedure for One-Way Analysis of Variance

i. Calculate the correction term $C = T^2/Kn$

ii. Calculate SS using the computing formula:

$$\sum_{i=1}\sum_{j} X^2{}_{ij} - T^2/Kn$$

iv. Calculate SSE by subtraction (SS - SST)

v. Calculate the degree of freedom (df) associated with SST and SSE.

vi. Calculate the best estimates of the population variance (Mean Square).

$$\alpha^{2}{}_{t} = \frac{SST}{K-1}$$

$$\alpha^{2}{}_{p} = \frac{SSE}{K(n-1)}$$

vii. Compare these two estimates by calculating

$$F\text{-}_{ratio} = \frac{\alpha^{2}{}_{t}}{\alpha^{2}{}_{p}}$$

viii. Compare with $F_{0.95,(v1,v2)}$

where $v_1$ = df associated with SST and $V_2$ df associated with SSE.

ix. If $F\text{-}_{ratio} > F_{0.95,(v1,v2)}$, reject the null hypothesis and conclude that there are significant differences.

The analysis is performed more easily by setting up an ANOVA table as shown in the text, for example table 5.1.

4.0 Procedure for Two-Way Analysis of Variance

i. Proceed as in 3.0 above and calculate SS, SST, SSB and SSE.

Note that here SSE = SS - SST - SSB. Also the degree of freedom associated with SSE is df(SSE) = df(SS) - df(SST) - df(SSB).

ii. Separate F tests are then performed on both between treatment (SST) and between block (SSB) variances. The tests are facilitated by setting up a two-way ANOVA table as such table 5.7.