*Faculty of Engineering*
*and Applied Science*

*Master of Engineering*

GROUP DESIGN PROJECT

# MOLE DRAINS

R. DRURY   L. LE PEN

University
of Southampton

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# .SUMMARY REPORT

## . OBJECTIVES

The objectives of this group design project was originally to attempt to understand the efficiency of a promising new technology in land drainage, NFDC's "Mole Drains", whose only current site of installation is in the cliff slopes in Christchurch Bay, Hampshire. It was hoped that the group would be able to come up with a design procedure for the placement of the drains based on parameters of site specific conditions.

However it was quickly realised that their was not sufficient data on the Mole Drains to achieve this, more general objectives were set in terms of understanding how the cliff slopes were failing and how the slope could be stabilised by reducing its internal pore water pressure. This is achieved by utilising a slope stability analysis on the undercliff and a water balance calculation for the surrounding area.

The findings of these studies will provide essential results for the understanding of how the cliffs are failing and what needs to be done to prevent slope failure in the future. Examination of the current data available on Mole Drains has also enabled recommendations to be made for future research required in order to progress understanding of how they operate and what could be done to improve on the current guidelines for placement.

## . RESOURCES

The NFDC provided the information and data related to the cliff slope and the Mole drains at Barton-on-Sea on request by the group. The NFDC granted permission to lease with the other parties responsible of the creation of the Mole drains to obtain further details:- geotechnical consultants (Rendel Geotechnics) and the contractor (A.E. Bartholomew).

The service from the Mechanical Design Faculty at Southampton University enabled manipulation of NFDC's AutoCad survey drawings of the Barton-on-Sea area.

The project involved various site visits to the Barton-on-Sea Cliffs and several of the visits were accompanied by an NFDC representative including a visit during a Mole drain flow monitoring exercise, which proved vital to the projects direction.

## . CONSTRAINTS

Originally it was envisaged that the project was to be undertaken by a group of three members. However, the third member, unbeknown to the rest of the group, did not continue into the fourth academic year. Not only did this result in a reduced group, but the private study during the preceding vacation by this third member was lost placing the group behind schedule on researching.

The initial objectives, set by the Supervisor, for this project was based on information and data already available from NFDC. This information and data was found to be largely insufficient to compete the original tasks. This set back was not fully recognised until late November, almost two months into the project, this was due to the slow responses by NFDC to queries and requests for information. The data was firstly promised by NFDC, it was then revealed that much of the data for the mole drains had not been recorded. Further set-backs caused by inadequate flow monitoring techniques on the Mole drains adversely affected the relevance of this project to the actual drains.

The revised project objective entailed a slope stability analysis, where it was envisaged that a computer package, “Slope”, on the University Network would be used. However, it was found that the “Slope” package contained running errors and could not be utilised. No other computer package was available which resulted in the analysis being done by hand calculation. A long duration was spent studying, understanding and setting-up the data for “Slope”, which resulted in the analysis stage being behind schedule.

No computer package is available for 3D analysis of drainage, as is experienced in Mole drains, thus the analysis in this project was based on 2D theory.

A laboratory model for the study of the mole drains was unfeasible due to the high cost implications. Also the prohibitive cost of weather data from the MET office hindered the analysis of the Water Balance calculation.

## . APPROACHING THE TASK

As the project was predominately determined by the constraints, as outlined above, the planning of the project was difficult due to the continuously changing objectives. However, as the project objectives altered the tasks were separated and allocated a duration for completion. This planning, written using "Microsoft Project" was used as a project Management tool to ensure all the specified tasks could be completed in the time available. See Appendix D for copy of Project Plan.

A budget was also planned where a £525 budget allocation was provided by the MEng office. NFDC allowed access to their library and provided copies of any reports, drawings and disks of monitoring data without cost. See Appendix D for copy of Budget Plan.

## . TEAM ORGANISATION

### PROJECT ROLES

Treasurer - R. Drury        Secretary - L. Le Pen

### ADMINISTRATIVE ROLES

The tasks of research, analysis and write-up were evenly divided in quantity between the two group members.

### AUTHORSHIP OF REPORT

| | | | |
|---|---|---|---|
| Summary Report | Le Pen & Drury | **1.0** - *Introduction* | Le Pen & Drury |
| **2.0-2.2** - *Background* | L. Le Pen | **2.3-2.4** - *Background* | R. Drury |
| **3.0-3.2** - *Mole Drains* | R. Drury | **3.3** - *Mole Drains* | L. Le Pen |
| **4.0** - *Water Balance Calc.* | L. Le Pen | **5.0** - *Slope Stability* | R. Drury |
| **6.0** - *Future Work* | L. Le Pen | **7.0** - *Conclusions* | Le Pen & Drury |

## . CONCLUSION & RECOMMENDATIONS

Application of Janbu's semi rigorous slope analysis reveals that the drainage schemes in place must at all times be sufficient to draw down water levels to maintain the average pore pressure $R_u$ below 0.41 to prevent failure. Geologically this applies specifically the Chama Bed and the "F" plane, thought to be responsible for the slip failures experienced.

With the instability occurring along this stretch of coastline since late 1997 it is clear that drainage measures in place are not sufficient for extreme conditions.

The water balance calculation identifies that water draining from this stretch of cliff could have fallen as rain as long as three months previous. It would be realistic therefore to put this area on alert for landslip after three months of consecutive torrential rainfall have accrued. Torrential rainfall could be considered to have occurred if monthly totals approach or exceed 100mm per month or the three month total approaches or exceeds 300mm. Though it would be wise to exercise judgement over this definition since groundwater recharge, amount of surface flow and type of rainfall event will all affect the amount of water entering the ground.

Unfortunately the ultimate aim "to produce a method for the design and placing of these drains" has proven beyond this project, not least due to the complexity of the three dimensional problem, but also because there is a dearth of valuable information on the subject. It is hoped that the production of this report will act as a stepping stone to achieving this ultimate objective.

MEng GROUP DESIGN PROJECT

# Mole Drains

April 1998

**Supervisor:**

Dr M.E. Barton

**Second Examiner:**

Dr. Pitts

**Project Team**

Richard Drury - Civil Engineering
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# . ABSTRACT

This report focuses on a new development in cliff drainage technology, namely that of Mole Drains. Construction of Mole drains is trenchless, therefore minimising environmental disturbance and crucially, is also cheaper than more conventional cliff drainage methods.

This new cliff drainage technique currently has only one area of installation, (in Christchurch Bay), placed in 1994 these drains have been drawing out cliff water, in copious amounts until present. While there is no doubting this practical evidence that the method does drain water, no understanding of how effective the Mole Drains are in stabilising the cliffs exists. Furthermore, no procedure for the design and effective placing of a system is available due to its theoretical complexity. Therefore progress towards designing these systems for specific cliff drainage schemes can only be made through studies of installed systems.

This report examines the slope stability of the cliffs and attempts to ascertain what contribution the Mole Drains have made. Two analytical tools are primarily utilised to accomplish this. Firstly a water balance calculation has been made along the stretch of coastline between E423100 to E423900 (adjacent to Barton-on-Sea), and secondly a slope stability analysis relying on Janbu's semi-rigorous method has been made.

The water balance has shown that this area is very prone to slippage because of greater seepage flows in this area than adjacent coastline, the calculation also demonstrates that the inputs and outputs as caught by the drainage systems in place are reasonably in balance. The stability analysis has identified the slope would consistently exceed equilibrium conditions and slip annually without any cliff drainage measures in place, even with the remedial measures in place it is clear that these are not sufficient during extreme conditions.

It is hoped that this project will further progress towards the creation of design procedures for the placing of Mole Drainage Systems where they are appropriate and further understanding of the stability of the soil cliffs at Barton-on-Sea.

# . ACKNOWLEDGEMENT

We would like to thank the following people for their contributions to the project:

Dr Barton for his guidance and support throughout.

Dr Pitts for his interest in our work and for acting as second examiner.

Steve Fort of Rendel Geotechnics for taking the time and trouble to respond to our enquiries.

Andrew Bradbury and Steve Cook of The New Forest District Council for supplying the project with invaluable information and allowing us access to their library.

We also recognise the Ordnance Survey for various maps that appear within this report.

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# 1. INTRODUCTION

Over the past half century the cliffs and slopes by the coastal town at Barton-on-Sea in Hampshire, Southern England have been receding and at present the retreat has the potential of threatening the safety of the urban area lining the cliffs.

The cliffs comprise clay and sand layers, as such the cliffs are inherently unstable, however this instability has been amplified by the effects of water seeping through the soil creating pressure.

This project focuses on the instability of the cliffs and attempts to estimate/understand the efficiency of the drainage measures currently in place. In particular that of a new stabilisation technique whose only practical installation exists within the Christchurch Bay area. The new technique was developed in 1994 by the New Forest District Council (NFDC) together with Rendel Geotechnics (consultants) and A.E. Bartholomew (contractor), this system was thought up as a viable alternative to expensive conventional measures. It is named "Mole Drains" because installation of the drainage pipes requires no dug trench.

The development was catalysed in response to a new understanding of the failure modes at work in the cliff (by Rendel Geotechnics) when it was realised that the failure mechanisms were too deep seated for the then in place cliff drainage measures to withstand. The cost of conventional measures which would be sufficient to stabilise the area are prohibitively expensive.

Mole Drainage technology has wider implications if it can be proven, particularly in today's society where increasing environmental awareness has meant that past engineering practices are being dropped where possible in favour of practices which will minimise environmental intrusion.

These experimental drains and others within the undercliff are the main components investigated in this study for the stability of the cliff's at Barton-on-Sea.

The cliff's land drainage remedial measures investigated in this study include:

- **French Drains** - Placed perpendicular to the cliff face.
- **Main Drainage System** - Cut-off sheet pile wall parallel to the cliff face.
- **Mole Drains** - New technique for land drainage.

These remedial measures are concerned with the removal of groundwater within the cliff, thus reducing the pore water pressure within the strata and increasing the stability of the land. The other measures utilised to stabilise the cliff at Barton-on-Sea, such as Rock Groynes & cliff toe supports, are not of direct interest for this project.

Trial installations of the Mole Drains were put in place during 1994 with monitoring procedures recommended to determine how well the scheme would function. It was the initial intention for this project to establish the efficiency of the system from these monitoring records. However, early research into the information and data available on the Mole Drains indicated that a performance rating for the efficiency of a Mole Drain to extract groundwater from the undercliff was not feasible. New objectives were set considering the drainage measures as a whole and their contribution to the cliff stability. This was achieved by breaking down the core elements of the problem and utilising two analytical tools:

1. Using a water balance calculation to establish the amount of water percolating into the area around the cliff and comparing this to the measured amount caught by the drainage systems which have been monitored regularly by the NFDC since 1994.

2. Calculate the slope stability in relation to the estimates of water content within the undercliff. This has been achieved with Janbu's semi rigorous slope stability technique.

In conducting these studies several topics concerning the stability of the cliff and the effectiveness of the Mole Drains can be discussed with confidence with topics for future research required outlined. Relevance of the monitoring procedures to understanding the Mole Drains and data available will be of particular interest to the advancement of the technology. This study will provide NFDC with information that can be used to improve the safety of the area and also help understand and develop the potential Mole Drains offer for an environmentally concerned society.

# 2. BACKGROUND: BARTON-ON-SEA

## 2.1 The Study Area

Barton-on-Sea is a town on the south coast of Hampshire near to the New Forest, as shown in Figure 4. This study is concerned with the cliff drainage schemes in place between Eastings 423100 and 423900.

The stretch of the coastline has been subject to recession caused by marine erosion and inherent slope instability. Left unchecked, over a period of decades, the recession would slowly overtake the small town.

*Figure 1 - Barton-on-Sea Coastline*

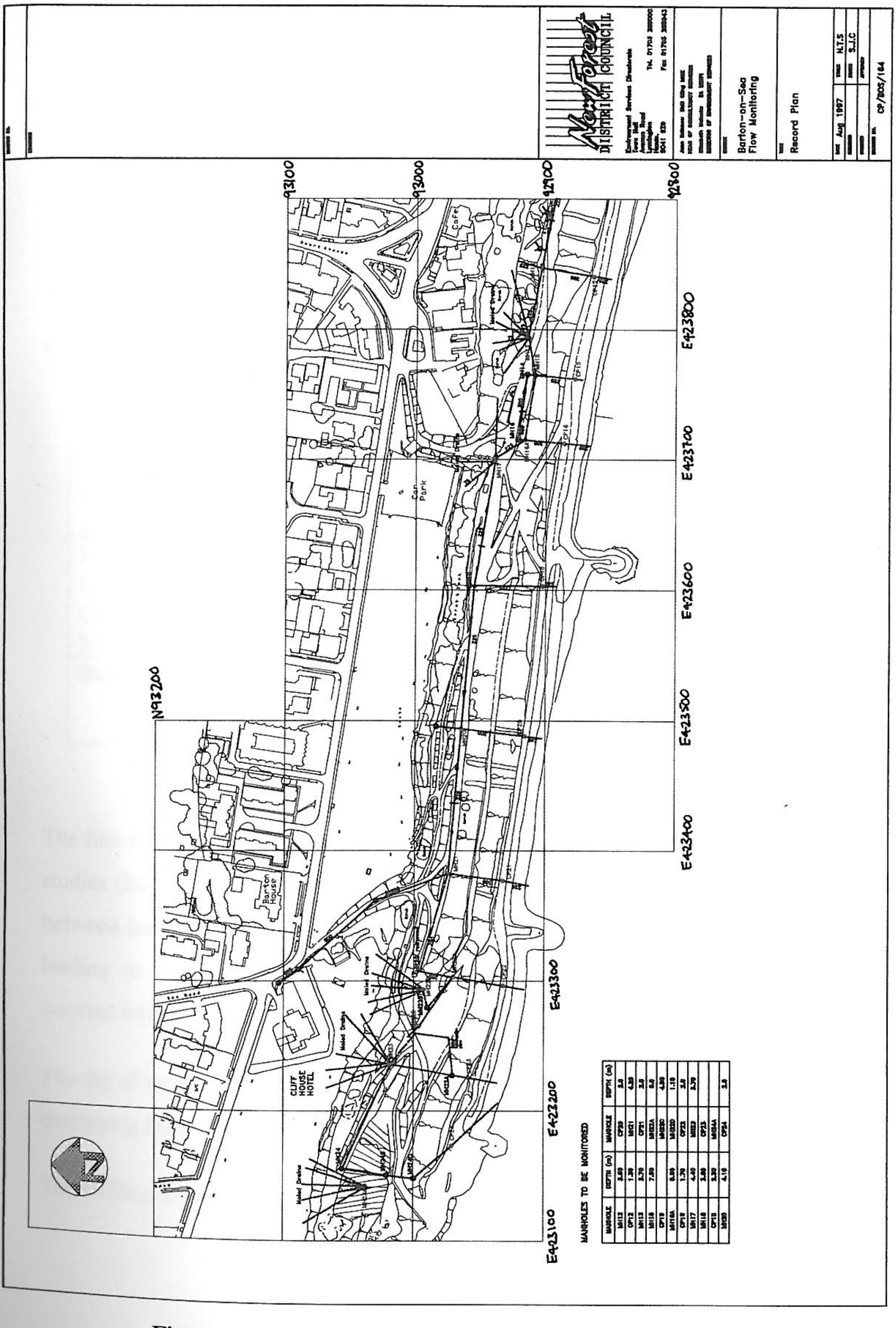
Despite the inherent instability of the cliffs, drainage and various cliff protection schemes have been in place along this stretch of coastline since the 1930's. Schemes have included regrading of the slope and the placing of armour along the shoreline to protect against wave erosion. The success of these schemes is arguable and their effectiveness may have been hampered by a lack of understanding of the geotechnical processes at work. Cost constraints have also played their part.

*Figure 2 - Rock Armour Protecting the toe of the Cliff from Marine erosion*

*Figure 3 - House at Risk*

Shown on Figure 5 is the stretch of coastline under investigation, with the general arrangement of the drainage scheme, this includes the older sheet pile scheme and the new Mole Drains with their fan like pipe arrays. The scheme is set up so that several drainage pipes flow into manholes, where the water then joins into one exit pipe which goes to a catchpit and then out to sea, with the exception of manhole 24A whose Mole Drained water is discharged elsewhere.

*Figure 4 - Barton-on-Sea cutting from OS 1:25,000 Tourist Map*



MANHOLES TO BE MONITORED

| MANHOLE | DEPTH (m) | MANHOLE | DEPTH (m) |
|---|---|---|---|
| MH12 | 3.60 | CP20 | 3.0 |
| CP12 | 1.30 | MH21 | 4.30 |
| MH13 | 3.70 | CP21 | 3.0 |
| MH15 | 7.80 | MH22A | 0.0 |
| CP15 |  | MH22C | 4.80 |
| MH16A | 6.80 | MH22D | 1.10 |
| CP16 | 1.70 | CP22 | 3.0 |
| MH17 | 4.40 | MH23 | 3.70 |
| MH18 | 3.60 | CP23 |  |
| CP18 | 3.30 | MH24A |  |
| MH20 | 4.10 | CP24 | 3.0 |

*Figure 5 - Existing Drainage Scheme, General Arrangement*

## 2.2 Geology and Hydrogeology

Several borehole logs exist in and around the Christchurch bay area and most recently an operation was commissioned in 1988 by the NFDC, which sited 6 boreholes within the coastal area of interest. Five of these were sited upon the undercliff while a single borehole was sited upon the clifftop. It is the records from this single borehole which represent the best knowledge of the undisturbed geology of the area of interest.

The study goes into detail that is not needed in this brief overview and the strata encountered is summarised in Table 1 below.

| Strata | Top (m A.O.D) | Base (m A.O.D) |
|---|---|---|
| Drift deposits and made ground (clay & sand) | 33.61 | 31.01 |
| Plateau Gravel (Gravel) | 31.01 | 27.21 |
| UpperBarton Beds (Fine sand) | 27.21 | 15.11 |
| Chama Bed (Silt and Clay) | 15.11 | 11.41 |
| Middle Barton Beds (Clay) | 11.41 | <3.56 |
| **Borehole data**: | Location = E423753, N092985<br>Borehole ends = 3.56m A.O.D.<br>Ground level = 33.61m A.O.D. | |

*Table 1 - General Arrangement of Strata*

The first three strata down to the Chama bed are considered to be permeable, though studies (Barton 1973) have suggested that there may be some discontinuity of flow between beds, i.e. lag time between water percolating across their boundaries. This leading to different hydrostatic pressures as observed by standpipe peizometers inserted into each layer.

The dip of the Chama bed has been estimated by Barton (1973) at 0.75° ENE with the overlaying beds varying in thickness up to the surface along the coastline and inland.

The clifftop along the study area remains relatively constant at 30m A.O.D.

Photographs Figure 6, Figure 7 & Figure 8 display the cliff face, as well as the undercliff formed of slip debris. The boundary between the Plateau gravel and Upper Barton Beds is plainly visible.

Problems arising in accurately ascertaining the exact arrangement of geology in the undercliff is discussed further in chapter 5 complications arise due to the slip debris and past regrading attempts to stabilise the cliffs.

*Figure 6 - Cliff-face*

*Figure 7 - Undercliff*

*Figure 8 - Undercliff*

The apparent dip East to West of the Chama and Middle Barton beds is estimated at 0.25° Barton (1973). With the level of the top of the Chama bed known at the borehole this would make the level of the top surface of this bed at approximately:

21.7m A.O.D @ E423100, N093000

14.7m A.O.D @ E423900, N093000

The difference at either extreme of the study area being seven metres.

The value of dip relies on observations of the visible Chama bed and boreholes on the undercliff West of the study area, as such the value should be treated with caution since the Chama bed is not visible within the study area.

## 2.3 Failure History

The failure history of the area indicated on the location plan, Figure 4, has been an ongoing saga of events with incomplete records. The extent and frequency of slope failure at Barton-on-Sea is uncertain up until the early 1900's, where gaps still appear in the records. It was not until the mid 1900's that adequate records of events started to take place. Thus the failure history of the cliffs at Barton-on-Sea can only extend back 50 or so years. Many failures have occurred within this period but only three were of major concern, they were as follows;

**1974** - **Barton Court** (423800E 92900N)

Large upper & lower cliff failure

**1988** - **Hoskins Gap** (423700E 92900N)

Lower cliff failure

**1993** - **Cliff House Hotel** (423250E 93000N)

Large lower cliff slip

## 2.4 Previous Studies & Remedial Works

As many there are failures, there have been studies commissioned on the Barton-on-Sea area over the last century. Again, the documentation of these studies and the remedial works following the studies are rare and often unrecorded. Despite this, it is considered that all previous remedial works before 1964 shall be dismissed on the grounds that they are no longer relevant. This is an acceptable assumption as several degradation events have occurred since 1964 that would render any pre-1960's remedial works ineffective.

Thus the remedial work on the slopes at Barton-on-Sea after 1960 of interest were as follows;

**1964-'68**

- Vertical timber piled revetment at cliff toe - To protect the cliff against sea erosion.
- Slumped cliffs reprofiled to form regular slopes, berms and tracks - To help stabilise the cliff slope.
- 1.1km sheet pile wall approximately 6m deep - Designed to intercept water passing through the cliff and drain using 24 outfalls at sea.

**1970**

- Five No. rock groynes - Placed to protect the coastline from sea erosion.

Even these remedial measures constructed in the 1960's and 1970's failed to withstand the test of time as by 1990 all existing works had been removed or replaced. The sequence of the failure of these events were as follows;

**1980's**

- Timber revetment eroded.
- Drainage system corroded and collapsed in several places.

The major failures that occurred over the period where these post-1960 prevention measures were implemented lie close to the sites of failure of the remedial works. The recent works on the Barton-on-Sea cliffs in the last decade have concentrated on replacing much of the work done during the 1960's. During this period more site investigations were commissioned by the NFDC, such as Halcrow's (1987) report recommending permanent remedial measures at Hoskins Gap. Some measures were taken to protect the cliff and undercliff from erosion, unfortunately with no major long term stabilizing effect. Rendel Geotechnics throughout the early 1990's, on behalf of NFDC, conducted several surveys of the area in terms of the stability of the slopes. It was identified that further remedial preventative measures were required if the Barton-on-Sea cliff and undercliff were to remain stable or within tolerable limits and control. The remedial measures that have taken place within the last decade are listed below. Through regular visits and monitoring, all of the remedial measures during this period are in working order. However, major slippage has taken place within the undercliff since their installation which has affected the performance of all these measures.

**1990**

- 1960's timber revetment replaced with 1 in 3 Blockstone - To protect the cliff toe against wave attack.

**1991 & 1994**

- Replace 1960's drainage system - By A.E. Bartholomew
- Investigation into the slope stability at Barton-on-Sea by Rendel Geotechnics. The findings of this study instigated the necessity, concept and placing of NFDC's experimental Mole Drains.

These past and most recent studies, surveys and reports conclude the scope of information utilised for the purposes of the history profile of the Barton-on-Sea cliffs .

# 3. MOLE DRAINS

## 3.1 Drainage Schemes

Drainage systems have been used to stabilise areas of instability for decades, if not centuries. The most common and traditional method of land drainage is the rock filled drainage trench. Trench drainage is becoming less popular due to its high construction time, high cost and its impact on the environment. In recent years the subsequent development of other techniques considering these factors have produced the likes of permanent Pumping and Horizontal drainage systems. These two methods, although perfectly capable of reducing pore pressures within slopes, cannot be achieved without major concerns and complications.

For example, the initial payment for the pumping equipment is high which would also require maintenance having a life expectancy of 5 or possibly 10 years. The Horizontal drains although cheap compared to the initial cost for pumping promote many concerns as to their reliability. Horizontal drains are single entry, up or downward sloping, pipes inserted into a cliff/slope face. The problems arise with time, in most ground conditions the pipes block with the flow of fine sediment and require maintenance and cleaning. Over long distances, cleaning and maintenance prove difficult, some times impossible, thus rendering this technique a non-viable long term option for slope stability.

These three examples are by no means the only measures for slope stability and the reader is directed to Hutchinson (1977) for a summarised review of general stabilization methods.

## 3.2 Mole Drains

The New Forest District Council, Rendel Geotechnics and A.E. Bartholomew, all involved with the Barton cliff stability programme, combined theories of how the water seepage bypassing the sheet piled drainage system could be drained. This was investigated when surveys revealed that the slopes were not totally stable after the replacement of the main cliff drainage during 1991 & 1994 and the free water was causing slumping of the saturated cliff.

The installation of a moled, perforated land drain was proposed. This technique of land drainage was new and unknown in its performance. Nevertheless NFDC commissioned an experimental trial single moled land drain during January 1994.

### 3.2.1 The Principal of Mole Drains

The initial purpose for the Mole Drains were to assist in the land drainage, collecting the escaping surface water missed by the existing main system.

The principal of the Mole Drains' profile is unique and the affects are not fully understood. It is the objective of this project to further the knowledge and thus give a better understanding of how the Mole Drains work.

The concept of Mole Drains is relatively simple. Figure 9 shows the profile of a Mole Drain inserted to a section of cliff, entering through the undercliff and exiting at the cliff top. The profile should be practically horizontal through the undercliff and once sufficiently passed the cliff face, the profile changes. The Mole Drain then turns vertical towards the cliff top with the bend having a designed radius.

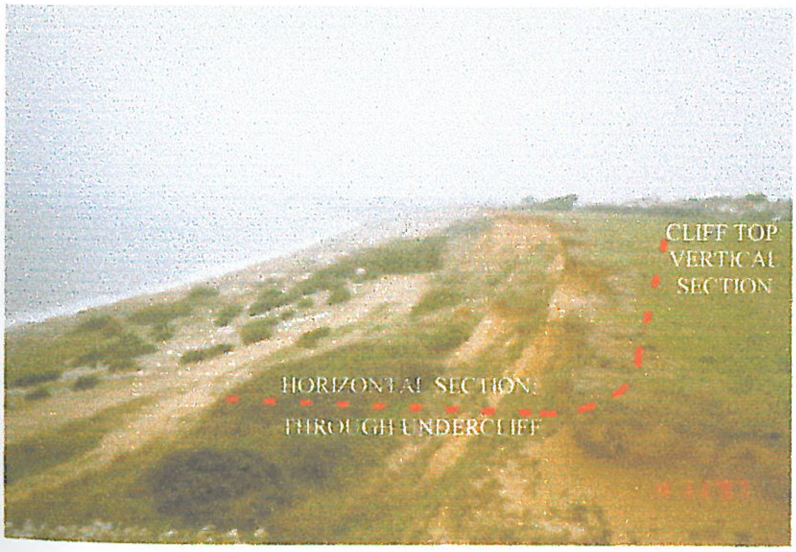


*Figure 9 - Typical profile of Mole Drain through cliff from undercliff to cliff top*

It is believed that the initial horizontal section of the Mole Drain acts in a similar manner to that of the traditional Horizontal drainage system where the pipe inclination and surrounding strata are predominant influences to the drains performance. The vertical or near vertical section of the Mole Drain acts akin to the effect offered by gravity induced vertical drains. The bend connecting the horizontal and vertical sections has unknown influences or effects on the water being drained. It is unknown whether the water attracted by the vertical section is passed along to discharge down the horizontal section or if it percolates back into the strata in the vicinity of the bend. The actions of leaching, suction, strata & pipe permeability, groundwater pressures and many others are all possible parameters that could effect the direction of water flow around the bend.

The type of drainage pipe used for the experimental Mole Drains consisted of a 75mm outside diameter medium density polyethylene (MDPE) continuously welded pipe. The perforations required for water attraction were provided by 10mm diameter holes hand drilled on site at 75mm centres.

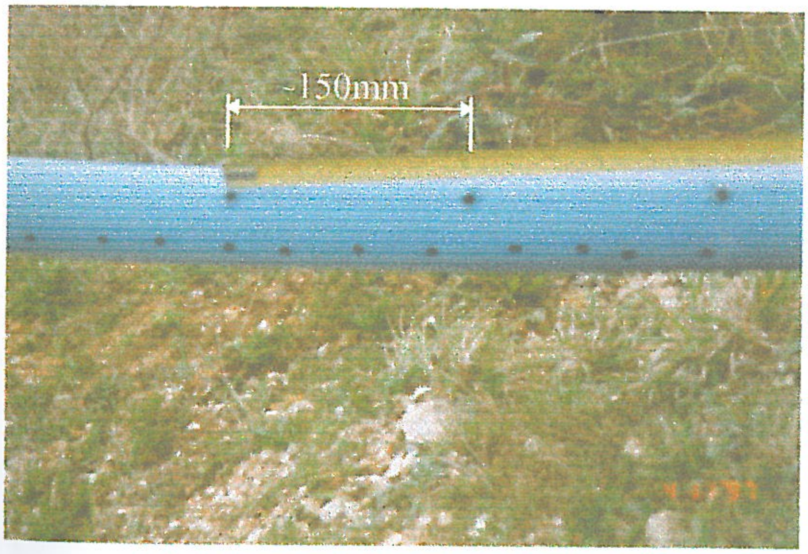


***Figure 10 - Typical section of hand drilled perforated MDPE Mole Drainage pipe.***

Standard pre-perforated pipes had been tested without success, as their tensile strength were not designed for the installation technique as described in the following section. For this reason hand drilled pipe were used and as Figure 10 displays, the arrangement of the holes are very crude and not to the specified dimension. The adverse affect to the drainage efficiency is unknown where the determination of the effects is beyond the scope of this project.

The initial anticipated effect expected by the NFDC, through the installation of the Mole Drains, would be that they should reduce the long term pore water pressure distribution in the immediate vicinity of the cliff face. As a result of a reduced pore water pressure the stability of the cliff will be improved, but to what amount?

The understanding as stated above is an assumption as believed by the group and requires further investigation through detailed studies and model analysis.

### 3.2.2 Installation: Mole Drains at Barton-on-Sea

The term "Mole Drains" is due to their unique installation technique. A steerable oscillating mole connected to a hydraulic ram, fixed in location at the bottom of the undercliff, is driven into the slope in 1 meter length intervals using steering rods. (See Figure 11 and Figure 12 pictures of the "Grundohit" hydraulic ramming Machine) This performance provides the hole in which the drainage pipe can be inserted.

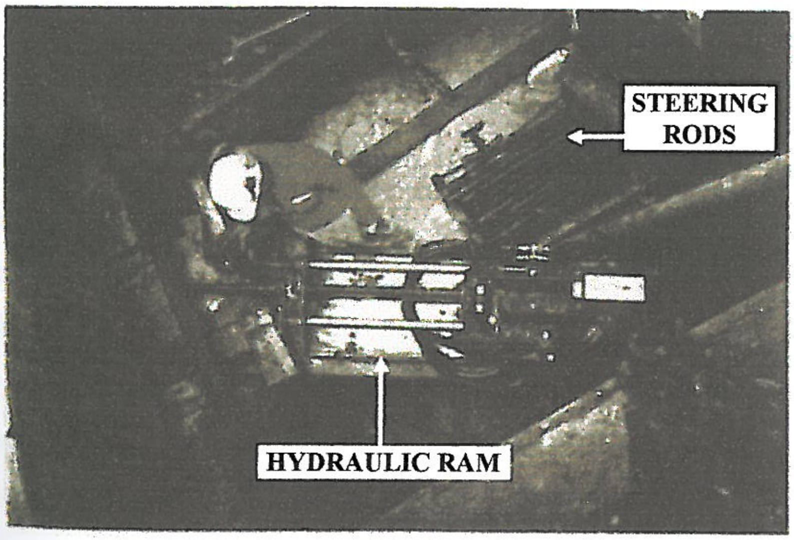


*Figure 11 - Plan view of "Grundohit" hydraulic ram, as used by A.E. Bartholomew for the installation of the experimental Mole Drains.*

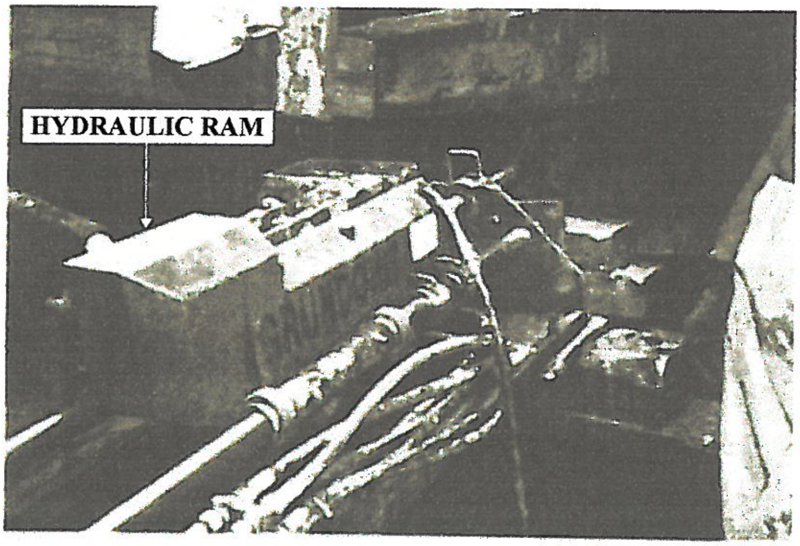


*Figure 12 - Elevation view of "Grundohit" hydraulic ram.*

A diode target is fixed to the first steering rod connected to the mole where directional control for steering is achieved by the ramming machine while using tracking equipment above ground. The tracking equipment can locate the diode target in both horizontal and vertical alignment. This allowable steering enables the mole to be steered through a desired profile within the undercliff and exit at any location in the cliff top.

Once the mole has reached it's destination, i.e. the cliff top, the mole head and diode are disconnected and a perforated land drainage pipe is securely connected to the front steering rod. To insert the drainage pipe into the moled hole, the hydraulic ram is reversed pulling the steering rods as well as the drainage pipe down back through the hole. Where the desired location of the pipe is achieved, a manhole may by constructed, for purposes of inspection and maintenance. These manholes, for various arrangements of Mole Drains along the undercliff, are connected together by a main drainage system which discharges out to sea.

The ends of the pipe not protected within the manholes, i.e. at the cliff top end, are capped enabling access for maintenance rodding and jetting to be undertaken when required.

### 3.2.3 Cost: Mole Drains at Barton-on-Sea

The implementation of Mole Drains has an environmental supremacy over the traditional trench drainage for it's no-dig-technique, leaving the majority of the landscape untouched. The installation time, even for the experimental trial, proved quite short taking less than 5 days to install the first four Mole Drains with a total length of 115m, substantially quicker than installing trench drains. It should be noted that a trench drain in this location would require the removal of soil to a depth of 2.5m - 3m by at least 1m wide.

The total cost for the installation of the first set of four Mole Drains in January 1994 cost approximately £10,000 for a total pipe length of 115m. This cost incurred for this experimental section was exaggerated due to the high risk to the Contractor. The second set of Mole Drains installed in May 1994 cost £10,000. This time the set contained five drains with a total pipe length of 170m where one pipe extended 60m through the cliff.

As the Mole Drainage technique is still in it's experimental stage the cost and extent of maintenance is unknown. However, the frequent flow monitoring undertaken by NFDC since installation indicate that annual rodding and jetting would be adequate, with the potential of being a biannual event.

## 3.3 Records and Their Credibility

The NFDC hold records specific to the area, in addition to this the project required the acquisition of climatic data, specifically rainfall but also other measures such as wind, temperature and relative humidity in order to formulate a credible water balance calculation.

### 3.3.1 Climatic Data

Initially approaches were made to the MET office as regards obtaining data from climatic monitoring stations which they run in the Barton-on-Sea area, however it was found that the cost was prohibitive. Costing £675 plus VAT per station, this included an educational discount without which the cost would have reached £5100 + VAT per station.

With this avenue closed to the group, further investigation revealed that hand written records from the Everton station would be obtainable at only the cost of a trip to pick them up. These records were the same as those which the MET office would have supplied, except that they were not in a digital format, nor over such an extensive period as had been originally requested.

These records are on a daily basis, the station itself was well situated and after inspection the group has full confidence in the records obtained. They include very detailed information, not all of which has been utilised.

### 3.3.2 NFDC Monitoring data

The NFDC have been monitoring flow through manholes, and ground conditions along the stretch of coastline in question intermittently for several years. Records exist for flow rates as well as survey records of movement for various studs placed in the ground, and monitoring of several peizometers installed. Unfortunately the data is of questionable accuracy.

All the raw data made available to the group by the NFDC that was utilised in this project is included as part of Appendix C. Comments have also been added to explain where water is flowing to and from, and also the group's opinion on its reliability.

#### Flow Monitoring

The flow monitoring was initially undertaken by a private firm subcontracted to the NFDC. They took readings on a weekly basis for most of the pipelines in this area between May 1995 to April 1996. Close scrutiny of the monitored data reveals some inconsistencies with some highly unlikely results. For example, discharges being the same every week for months on end, sudden rises in discharges, opposing trends between pipes, (one rate increasing over a period whilst another decreases), all with no apparent explanation. The NFDC terminated the subcontract for these reasons. There is then a gap in the records until February 1997 when monthly monitoring by the NFDC was initiated This has continued until December 1997 with only a few months missed, at which point the whole area became subject to instability and monitoring was discontinued for safety until present, (April 1998).

The monitored flows include all the Catchpits (CP's) and most of the flows into the manholes as shown in Figure 5. Care must be taken to interpret this information. Things to be aware of include:

1. Some manholes are linked together so that some water is measured twice.
2. There are a number of pipes which have been found during the course of the monitoring program discharging into various manholes, for which no plans exist and are not shown on Figure 5. It is likely that these pipelines were included to pick up water which was perceived as being present during the piecemeal construction of the system. These are also monitored.
3. Highway water is thought to flow into manholes 16 and 21. It is not known as to the extent of this, but is unlikely to go beyond the two coastal access roads adjacent to these manholes.
4. Lastly, a culverted stream is thought to flow into MH21, this flow would appear to be of significance though where the stream originates from is not known.

The group accompanied the NFDC during their monitoring of the flows on 4th & 5th of November 1997 and during this task an experiment was undertaken to test the accuracy of the monitoring procedure. Normally for each pipeline a container of known volume is placed under the discharge, the time is measured for this to fill a certain amount (dependent on the discharge) and this is then converted into litres per minute and recorded. Usually this procedure is only enacted once for each pipe monitored but this time for three of the Mole Draining manholes the flow was measured three times and the range of values received compared. Additionally on the second day of monitoring this was repeated to detect any change in flows. The results of this experiment are shown in Appendix C. The variance can be as much (for same time readings) as 75% between the highest and lowest in one extreme case though, more commonly it will vary by about 20%. The difference between the readings between the averages of the two days showed less variance, the maximum being 18%.

Another complication in the monitoring, stems in fitting the container beneath the pipeline when it is close to the base of the manhole. In some cases monitoring is practically impossible and so no monitoring can be undertaken, in other cases it was difficult and introduced additional error potential.

#### Land Survey Monitoring

Control points have been placed in this area. These have been surveyed in from known stations, their co-ordinates and reduced levels have then been noted periodically to check for ground movement.

The survey data shows that there has not been any significant movement around the Mole Drains since Oct 1995 (when records begin) until September 1997 when the data was obtained by the group. Since Christmas of 1997 though, the whole area has been subject to instability.

#### Piezometer monitoring

The group have decided that the peizometric readings can be of no use to this project, because, though some seem reliable these are positioned in areas and strata's of no interest, i.e. in clay layers. When standpipes do coincide with the area under consideration the logs seem unreliable with jumps in readings of over 6 metres in some cases. This information though studied has not been relied upon for any calculations.

### 3.3.3 Position of Drains

The Mole Drains were placed in the areas of greatest instability in the hope that this additional measure in conjunction with the existing drainage schemes (as outlined in chapter 2) would stabilise the cliff against further movement.

Several Mole Drains go into a single manhole (as shown in Figure 5). It would have greatly increased the cost if manholes had been constructed for individual Mole Drains, so in order to cover the greatest area, the moles were dispersed in fan like arrays. This was purely for reasons of economy. The original intention was that there should not be more than twenty metres between the mole pipe exits on the clifftop along the areas requiring stabilisation (Rendel).

During their installation the Mole Drains were guided at all times through the undercliff to the exits which were decided upon by visual inspection. The most preferred arrangement was to have the moles exiting on the clifftop but where this was not possible, i.e. when the land was privately owned, and/or built upon, they exit upon the undercliff.

Despite the fact that during construction the exact location of the mole head in relation to the ground surface was at all times known, no records exist as to the profile of the pipelines between the manholes and their exits. The location maps for the moles which are in plan view were drawn by visual inspection.

As a consequence the project has not been able to look at what would be an optimum profile for a Mole Drain or the best arrangement for most efficient water extraction based on these specific working Mole Drains.

# 4. WATER BALANCE CALCULATION

## 4.1 Overview

The purpose of the water balance calculation is threefold.

1. To estimate the amount of water which is discharging from the cliffs at Barton-on-Sea. The calculation will also demonstrate if this area of coastline is subject to greater or lesser water discharge than the surrounding area. If this is proven or shown to be likely then it will explain why this stretch is prone to greater instability than the adjacent coastline. This objective is specific to Barton-on-Sea.
2. To compare the above to the monitored discharge rates, which will show if the drainage schemes are catching all the water which is believed to be present.
3. To determine the proportion of water the Mole Drains are taking out and how they compare in effectiveness to the more expensive sheet pile toe drainage scheme. This objective is specific to the drainage methods.

## 4.2 Basis of The Calculation

A water balance calculation is based on the very simple principle that for any defined area there will be inflows and outflows of water. The inflows must be equal to the outflows plus the change in water stored in the area thus:-

**[Inflows] = [Outflows] + [Change in storage]**

The inputs into the area consist of the precipitation which falls onto the catchment area, but less that water which is lost to evaporation and transpiration of plants as well as the water which goes directly into surface runoff without penetrating into the ground. Surface runoff includes the portion of water which goes into the urban drainage network. The inputs are referred to as "Recharge". The Outputs consist of the water which flows out of the cliffs at Barton-on-Sea. It will be assumed for this study that there will be little, if any, direct surface runoff, other than that going into the urban drainage scheme.

The stages of the calculation specific to this case can be broken down as shown in the flowchart Figure 13 below:

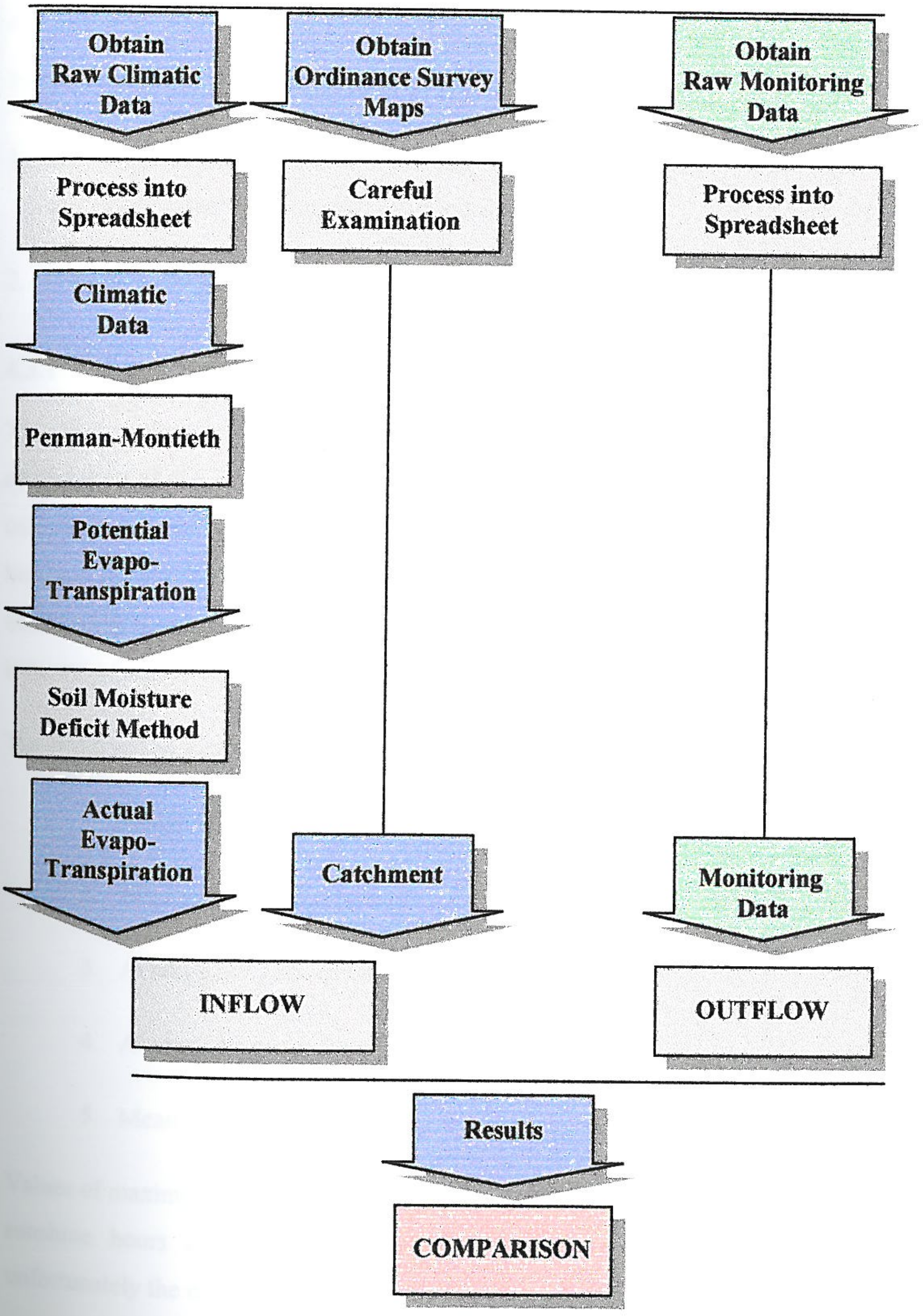


*Figure 13 - Water Balance Calculation Flow Chart*

The stages in the calculation will now be explained before the results are presented for comparison.

## 4.3 Inflows

The calculation of the inflows relies on two factors:

1. The climatic data obtained from the Everton monitoring station in order to ultimately calculate the actual evapotranspiration.
2. Making a credible estimate of the catchment.

### 4.3.1 Climatic Data

The Meteorological office monthly return of daily observations summary sheets obtained from the Everton station include information on a daily basis, but for the calculations it was decided that monthly data would be sufficiently detailed. This was because the NFDC records were at best only reliable on a monthly basis and the added work in making the water balance calculations for each day cannot be justified in terms of increased accuracy.

The information that was required for each month was:

1. Maximum daily temperature
2. Minimum daily temperature
3. Average daily run of wind
4. Average daily sunshine hours
5. Mean relative humidity

Values of maximum daily temperature, minimum daily temperature and average daily sunshine hours can be found directly from the monthly summary sheet but unfortunately the measures average daily run of wind and mean relative humidity had to be calculated manually. This was very time consuming since with records from Jan 1990 to September 1997 there were 93 separate monthly sheets to go through.

This information was processed into a spreadsheet ready for the next stage in the calculation.

### 4.3.2 Potential Evapotranspiration

This is the maximum amount of water which could potentially evaporate back into the atmosphere, for actual daily conditions (based on temperature, wind and relative humidity), provided that the ground is saturated and that plants are not dehydrated. The maximum potential will vary depending on the type of plant and is usually calculated for a typical grass crop.

The idea of potential evapotranspiration has been thought up as a mathematical tool enabling estimates of the actual evapotranspiration. It has a theoretical basis though in practice will never occur. It could be thought of as the evaporation occurring over an infinite body of flat water with filters limiting the amount to represent the resistivity of the plants and ground.

Several methods for calculating the potential evapotranspiration exist, most rely for their basis on the Penman equation, first published in 1963. For this study it has been decided to utilise the Penman-Montieth form of the equation. This equation is complex and will not be explained here (the reader is referred to the FAO report listed at the end of this report for full details). This form of the equation is recommended by the FOA, (Food and Agricultural Organisation of the United nations). The FOA arrived at the recommendation after performing a number of experiments and calculating the potential evapotranspiration utilising twenty different methodologies before concluding that this was the most accurate over the widest range of conditions.

The Penman-Montieth equation can be written:

$$ET_o = \frac{0.408\,\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2(e_a - e_d)}{\Delta + \gamma(1 + 0.34 U_2)}$$

Where: $ET_o$ : Reference crop evapotranspiration [mm d-1 ]

$R_n$ : Net radiation at crop surface [MJ m-2 d-1 ]

$G$ : Soil heat flux [MJ m-2 d-1 ]

$T$ : Average temperature [°C]

$U_2$ : Windspeed measured at 2m height [m s-1 ]

$(e_a-e_d)$ : Vapour pressure deficit [kPa]

$\Delta$ : Slope vapour pressure curve [kPa °C-1 ]

$\gamma$ : Psychrometric constant [kPa °C-1 ]

900 : Conversion factor

A spreadsheet utilised for this project and written as part of a Beng dissertation for calculating Penman-Montieth can be found on the Southampton University computer network.

The spreadsheet calculation for each year is included in appendix A.

### 4.3.3 Actual Evapotranspiration

The next difficulty is to convert this to the true amount of evapotranspiration in order to arrive at what is known as the effective rainfall, the amount of rainfall which will form groundwater flow.

To do this a relationship between soil moisture and ability of plants to transpire has been approximated.

Briefly explaining the terminology, the soil moisture is the surface layer of groundwater available to plants for nourishment, it is bounded at its base by what is termed the root constant, i.e. the level below which soil moisture will be virtually inaccessible to potential evapotranspiration (less than 10%). This value will depend greatly on the type of plant.

Another limiting factor on the amount of actual evapotranspiration is the rainfall. Although it is possible for more water to be absorbed into the atmosphere than the amount that falls as rain over a given period in a given area, it not likely to be significant so this added complication will be neglected.

To make the calculation requires consideration of the following assumptions:

1. The potential evapotranspiration is proportional to the soil moisture deficit up to the value of the root constant.
2. Potential evapotranspiration will be equal to actual evapotranspiration when there is no soil moisture deficit and rainfall has exceeded potential evapotranspiration.
3. Below the level of the root constant, actual evapotranspiration will be equal to 10% of potential evapotranspiration.
4. When rainfall is less than potential evapotranspiration, actual evapotranspiration will be equal to the rainfall in proportion to the soil moisture deficit.

With the actual evapotranspiration calculated, it is multiplied by the catchment area to obtain the total inflows.

### 4.3.4 Catchment

The area of catchment is particularly difficult to ascertain in this instance. No clearly defined river valley or vertical geological boundaries to flow exist. Further complication is introduced with the high degree of urbanised area and man's own interference in the natural flow of water through the area (culverting streams). Very little groundwater information is available for this area with the few piezometers that are in place having been discredited.

For this calculation to progress it is necessary therefore to make some reasonable assumptions.

The geology of the area is at least well known, the strata can be treated as almost horizontal. The Chama bed will act as a base boundary to flow.

This study has obtained the most detailed Ordnance Survey maps of the area available which show the topography and streams in the region. Figure 14 displays a photocopy for the area of interest. In conjunction with this the tourist map Figure 4 has also been studied, since it shows more clearly courses of streams. Together these have been utilised to produce the trace map Figure 15.

Figure 14 - OS Map of The Area (Reduction from 1:10,000 scale maps)

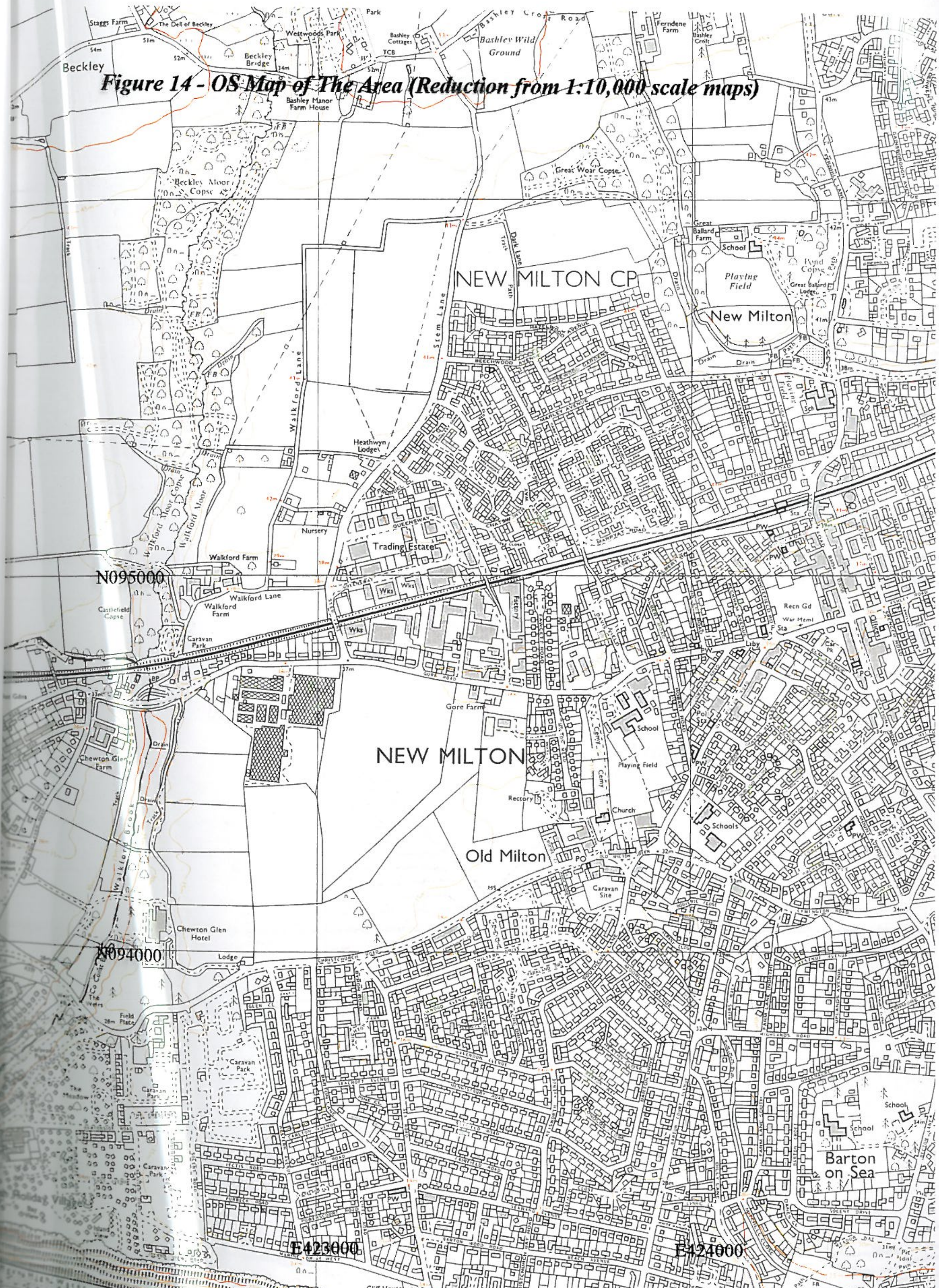
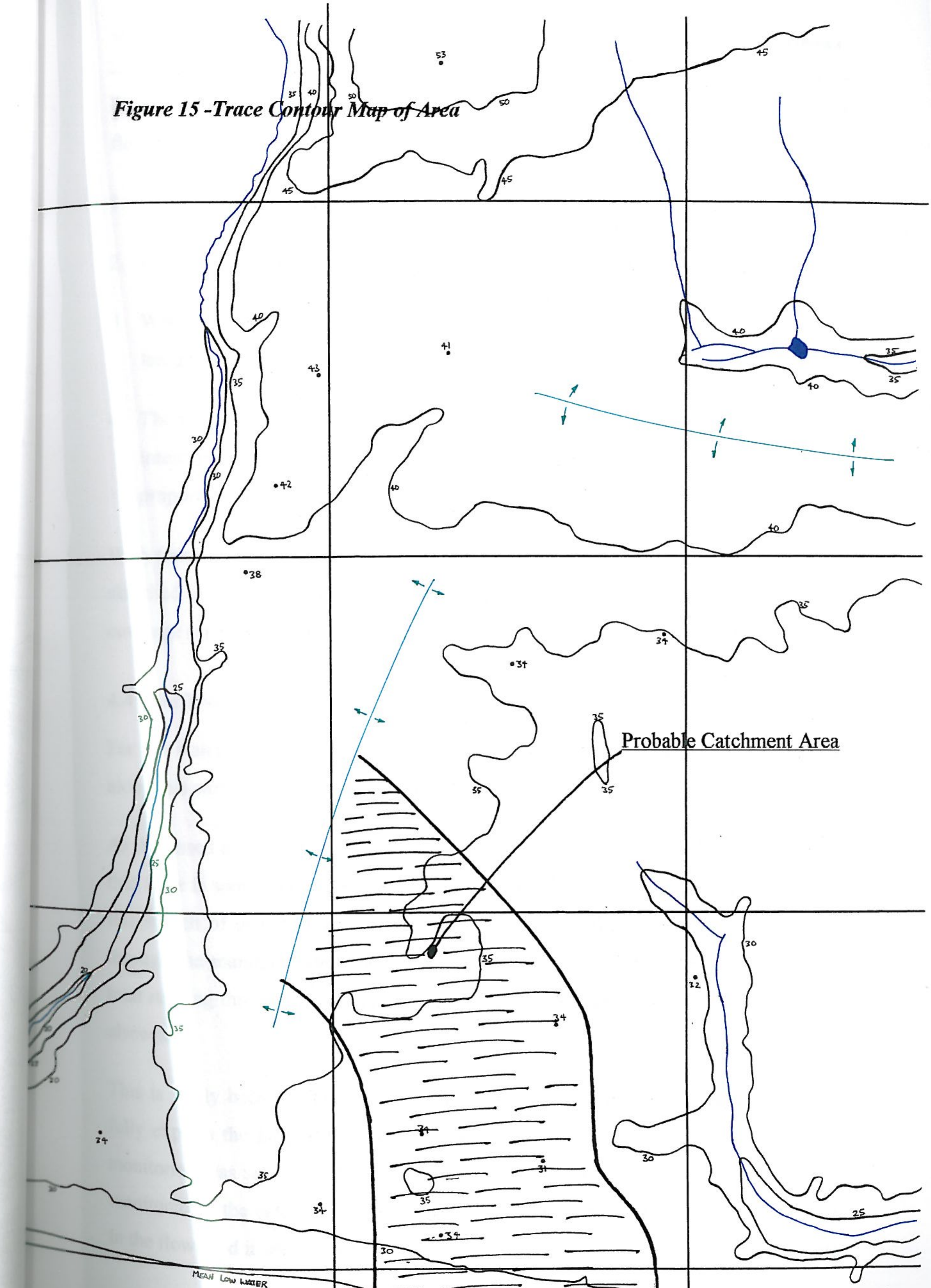


*Figure 15 -Trace Contour Map of Area*



From these two maps, it is possible to make some inferences about the direction of flow of groundwater. Firstly though the assumptions made need to be outlined:

1. At the level of streams the groundwater level is equal to the top of the stream.
2. Groundwater flow contours closely resemble topographical ground contours.
3. Where streams have been culverted (as these have at various points along their length), it is assumed that groundwater flow will still be drawn along these paths.
4. The local buildings will not serve to alter in any way groundwater flow except to intercept some water before it reaches the ground thus reducing the catchpit proportionally equal to the area of land within the catchpit that they occupy.

With these points in mind, drawn on Figure 15 in green are likely watersheds, and sketched in on the transparency is a possible catchment area. Allowing for the urban coverage (approx. 50%) this leads to an estimate for catchment of 475,000m$^2$.

### 4.4 Outflow

For the water balance calculation, the information of interest is the total discharge along this stretch of coast for each month that the data is available.

As discussed the NFDC monitoring data is imperfect. Processing of the data reveals that there is some conflict between the total amount of water being discharged along this stretch of coastline when calculated by summing the water measured running through the manholes, (making allowance for some being measured twice) and the total running through the catchpits, plus MH24A (see Figure 5) since this discharges elsewhere.

This is partly because some of the manholes have been missed, though it does not fully explain the large differences, particularly apparent during the time when the monitoring was subcontracted out. Looking at the data objectively the total flow as monitored by the catchpits seems the more reliable, there are not unexplained jumps in the flows and it seems homogenous between the two periods when different people were undertaking the monitoring. In respect of the Mole Drains themselves, this data seems reliable, as it would have been relatively easy to monitor with the narrower pipes allowing the container to be easily placed into the flow.

All the raw data can be found in Appendix C and some processing of the data to afford comparison has also been included.

## 4.5 Results and Discussion

The rainfall and effective rainfall data are presented in Table 2, Table 3 Figure 16, and Figure 17, the data is monthly from Jan 1990 to Sept 1997.

Ideally the period of calculation should be longer, (approaching thirty years to give high confidence) to pick up the most extreme climatic effects, and to predict a long term average. This was not possible in this case due to the massive amount of hand processing required. However even over the period of data recorded there is considerable variation.

The data includes the droughts of 1990 and 1996 which are considered to be some of the driest on record for the South of England. Conversely 1993 and 1994 were particularly wet years. This ties in with the failure which occurred during 1993 (see section 2.3 Failure History page 11).

The final results of the water balance calculations are presented as Figure 18 and Table 4.

| | Total Rainfall (mm) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Year** | | | | | | | | |
| **Month** | **1990** | **1991** | **1992** | **1993** | **1994** | **1995** | **1996** | **1997** | **Average** |
| **Jan** | 113 | 89 | 22 | 98 | 132 | 144 | 58 | 17 | 84 |
| **Feb** | 167 | 29 | 29 | 6 | 89 | 117 | 95 | 82 | 77 |
| **Mar** | 6 | 78 | 52 | 45 | 58 | 40 | 37 | 32 | 43 |
| **Apr** | 44 | 42 | 70 | 75 | 61 | 27 | 36 | 13 | 46 |
| **May** | 11 | 4 | 20 | 45 | 82 | 22 | 59 | 35 | 35 |
| **Jun** | 55 | 113 | 32 | 62 | 23 | 10 | 27 | 76 | 50 |
| **Jul** | 12 | 63 | 63 | 86 | 20 | 27 | 15 | 13 | 37 |
| **Aug** | 23 | 12 | 88 | 36 | 48 | 3 | 77 | 84 | 46 |
| **Sep** | 29 | 49 | 79 | 121 | 71 | 143 | 45 | 12 | 69 |
| **Oct** | 99 | 63 | 82 | 169 | 126 | 39 | 59 | | 91 |
| **Nov** | 54 | 49 | 145 | 64 | 91 | 144 | 132 | | 97 |
| **Dec** | 62 | 33 | 81 | 185 | 117 | 82 | 34 | | 85 |
| **Total** | 675 | 625 | 762 | 992 | 918 | 798 | 674 | 364 | |

**Total of Average Months 760**
**Average of Years 778**

*Table 2- Monthly Total Rainfall Jan 1990 to Sept 1997*

| | Effective Rainfall (mm) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Year** | | | | | | | | |
| **Month** | **1990** | **1991** | **1992** | **1993** | **1994** | **1995** | **1996** | **1997** | **Average** |
| **Jan** | 102 | 77 | 14 | 87 | 121 | 131 | 50 | 12 | 74 |
| **Feb** | 146 | 16 | 10 | 0 | 74 | 100 | 77 | 67 | 61 |
| **Mar** | 0 | 49 | 20 | 10 | 25 | 0 | 9 | 0 | 14 |
| **Apr** | 9 | 8 | 27 | 36 | 15 | 5 | 7 | 3 | 14 |
| **May** | 4 | 2 | 8 | 18 | 40 | 9 | 23 | 14 | 15 |
| **Jun** | 44 | 98 | 26 | 49 | 19 | 8 | 21 | 61 | 41 |
| **Jul** | 6 | 32 | 32 | 43 | 10 | 13 | 8 | 7 | 19 |
| **Aug** | 9 | 5 | 46 | 14 | 19 | 1 | 31 | 38 | 20 |
| **Sep** | 9 | 15 | 44 | 86 | 34 | 102 | 14 | 4 | 38 |
| **Oct** | 73 | 40 | 56 | 145 | 100 | 15 | 33 | | 66 |
| **Nov** | 39 | 33 | 131 | 49 | 80 | 128 | 115 | | 82 |
| **Dec** | 51 | 24 | 71 | 174 | 104 | 71 | 26 | | 75 |
| **Total** | 493 | 399 | 485 | 713 | 640 | 584 | 415 | 206 | |

**Total of Average Months 520**
**Average of Years 533**

*Table 3 - Monthly Effective Rainfall Jan 1990 to Sept 1997*

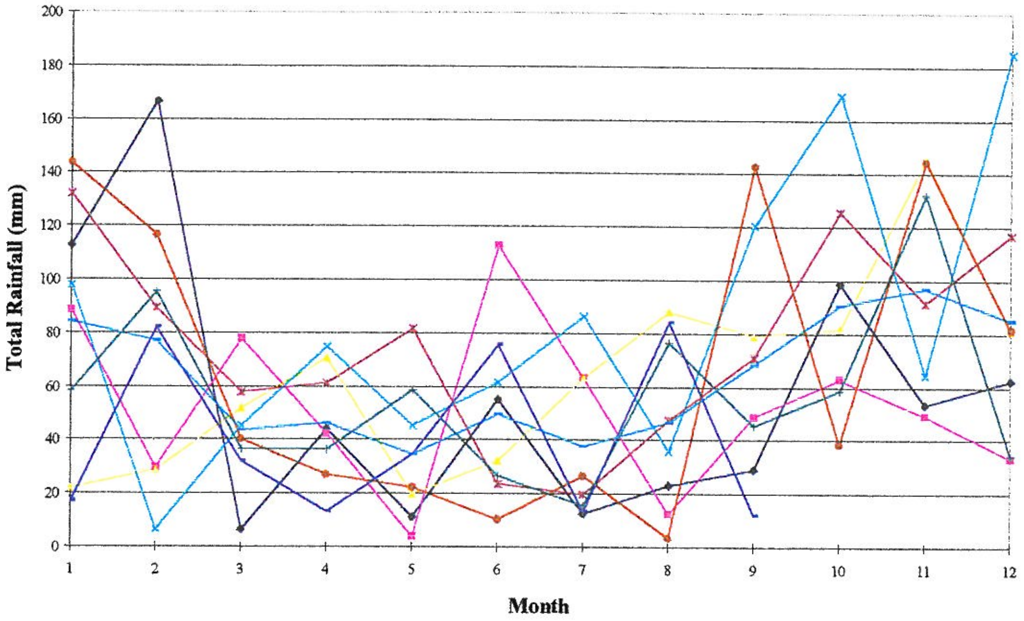


*Figure 16 - Graph of Total Rainfall Vs Month of Year Jan 1990 to Sept 97*

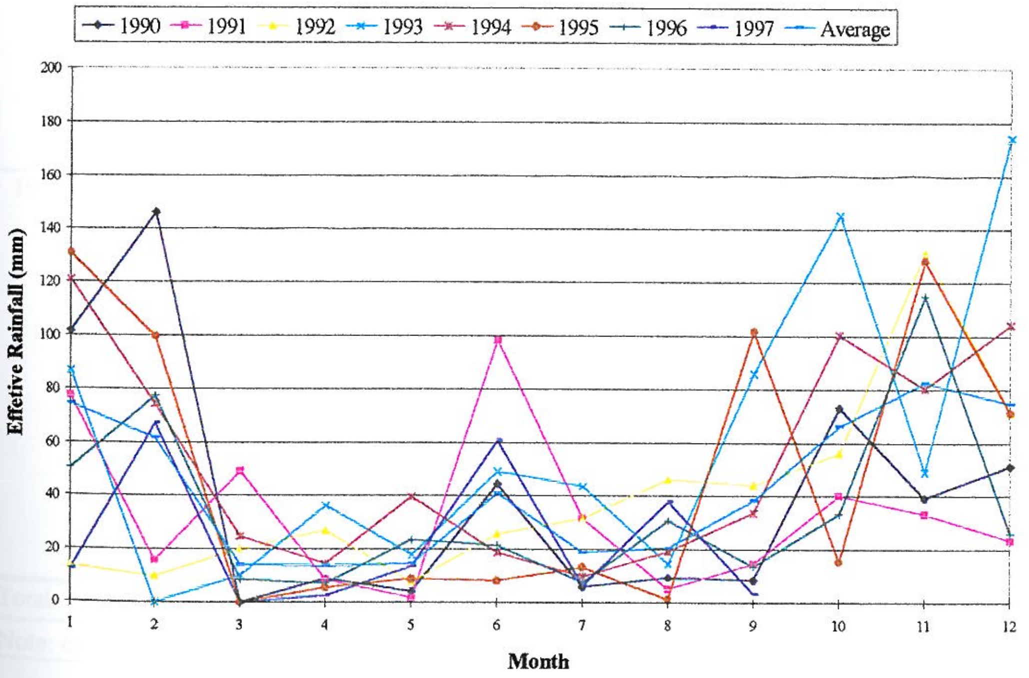


*Figure 17 - Graph of Effective Rainfall Vs Month of Year Jan 1990 to Sept 97*

Note: Legend is for both graphs

| Date | | INFLOW | | OUTFLOWS | | | DIFFERENCE | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Eff Rain | Total water | CP's + MH24A | Moles | | Same month | One month | Two month | Three month | Weigh-ted |
| | | mm | l/m | l/m | l/m | % | l/m | l/m | l/m | l/m | l/m |
| 1995 | Jan | 131 | 1390 | N/A | | | | | | | |
| | Feb | 100 | 1173 | N/A | | | | | | -796 | |
| | Mar | 0 | 0 | N/A | | | | | 377 | 372 | |
| | Apr | 5 | 60 | N/A | | | | 317 | 312 | 329 | |
| | May | 9 | 94 | 377 | 21 | 6 | 282 | 278 | 294 | 315 | 45 |
| | Jun | 8 | 89 | 372 | 20 | 5 | 283 | 299 | 321 | 296 | 311 |
| | Jul | 13 | 142 | 388 | 55 | 14 | 246 | 268 | 243 | 291 | 292 |
| | Aug | 1 | 14 | 410 | 103 | 25 | 395 | 371 | 418 | 428 | 325 |
| | Sep | 102 | 1118 | 385 | 77 | 20 | -733 | -685 | -676 | -654 | 44 |
| | Oct | 15 | 163 | 433 | 62 | 14 | 270 | 279 | 301 | 333 | 73 |
| | Nov | 128 | 1409 | 442 | 95 | 22 | -967 | -945 | -913 | -895 | -234 |
| | Dec | 71 | 759 | 464 | 103 | 22 | -295 | -263 | -245 | -184 | -398 |
| 1996 | Jan | 50 | 535 | 496 | 108 | 22 | -40 | -22 | 39 | 5 | -221 |
| | Feb | 77 | 912 | 514 | 104 | 20 | -399 | -338 | -372 | | -390 |
| | Mar | 9 | 93 | 575 | 107 | 19 | 482 | 448 | | | 0 |
| | Apr | 7 | 80 | 540 | 108 | 20 | 461 | | | | 135 |
| | May | 23 | 250 | N/A | | | | | | | |
| | Jun | 21 | 235 | N/A | | | | | | | |
| | Jul | 8 | 82 | N/A | | | | | | | |
| | Aug | 31 | 326 | N/A | | | | | | | |
| | Sep | 14 | 149 | N/A | | | | | | | |
| | Oct | 33 | 355 | N/A | | | | | | | |
| | Nov | 115 | 1262 | N/A | | | | | | -949 | |
| | Dec | 26 | 278 | N/A | | | | | 35 | 160 | |
| 1997 | Jan | 12 | 132 | N/A | | | | 181 | 305 | | |
| | Feb | 67 | 792 | 313 | 52 | 16 | -478 | -354 | | -501 | -303 |
| | Mar | 0 | 0 | 438 | 64 | 15 | 438 | | 291 | 298 | 137 |
| | Apr | 3 | 29 | N/A | | | | 262 | 269 | 291 | |
| | May | 14 | 147 | 291 | 49 | 17 | 144 | 151 | 173 | | 49 |
| | Jun | 61 | 667 | 298 | 53 | 18 | -368 | -347 | | -402 | 88 |
| | Jul | 7 | 70 | 320 | 49 | 15 | 250 | | 194 | | 92 |
| | Aug | 38 | 406 | N/A | | | | -142 | | -176 | |
| | Sep | 4 | 39 | 264 | 51 | 19 | 225 | | 191 | | -31 |
| | Oct | N/A | N/A | N/A | | | | | | | |
| | Nov | N/A | N/A | 230 | 46 | 20 | | | | | 4 |
| | Dec | N/A | N/A | N/A | | | | | | | |
| Totals | | | | | | | 195 | -242 | 1557 | -645 | 17 |
| Note: catchment = 475,000 m$^2$. | | | | | | | | | | | |

*Table 4 - Final Results of Water Balance*

The table displays inflows and outflows whose calculation has already been explained. Also introduced into the table is a calculation of the difference between the inflow and outflow, which has been calculated several ways, for the same months and lag times of one two and three months, the weighted difference has then been generated comprising the sum of the quarters of the first four measures.

The total difference (last row) represents the change in storage of the groundwater within the catchment area over the period of recorded data. This value should not be taken seriously due to the absence of many months data. However the values should not be too far from zero (no change in storage) if the catchment estimate is correct.

After some experimenting with the lag time calculation and the catchment area, the weighted value shown in Table 4 seems the most likely indication of change in storage.

The weighting represents the range of journey times likely for water which falls in the catchment area. Clearly water starting out at the far end of the catchment will take some time to arrive at the coast, whereas that which falls along the coastline will almost immediately be registered.

A graph (Figure 18) has been plotted for comparison of flows.

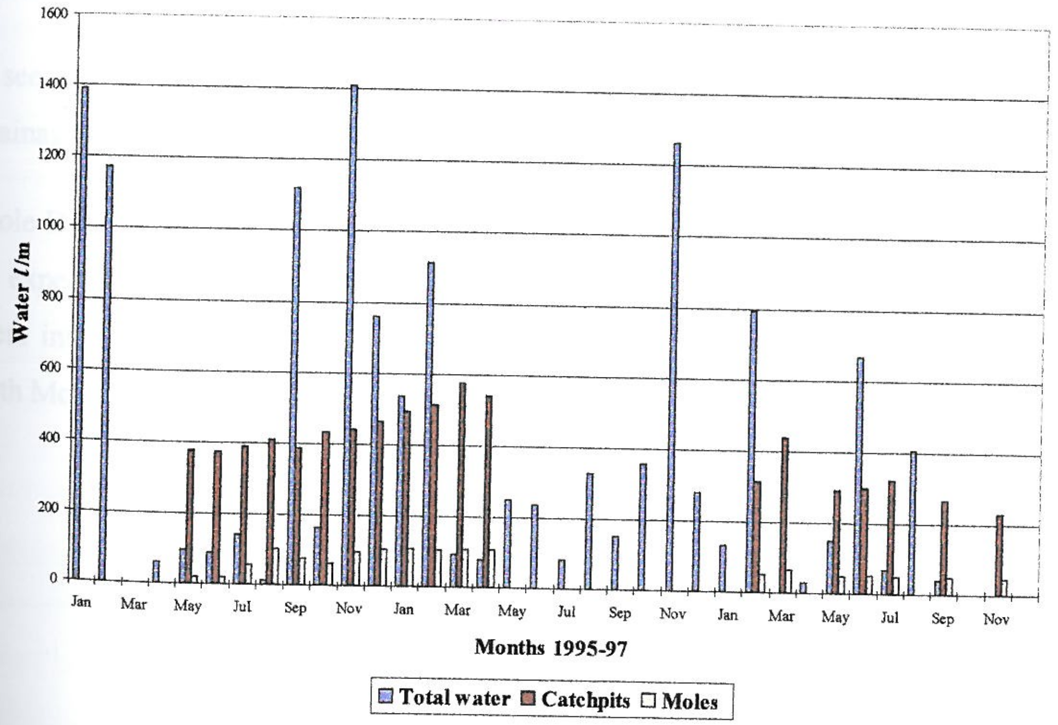


*Figure 18 - Comparison of flows*

Note when interpreting this graph: There is no total water data for Nov 1997 and there is no monitoring data prior to May 1995, or between and including May 1996 and Jan 1997, or for the months April, August and October of 1997.

Some trends can be inferred from the graph:

1. The outflows are not subject to dramatic monthly change as the inflows are.
2. The Mole Drains broadly agree with the trends set out by the total discharge, i.e. they do not seem more sensitive to changing inflow than the other drainage schemes in the area.
3. The idea of lag time seems to be born out by the chart, and the weighted estimate of the lag does not seem unreasonable.

### 4.6 Summary

The catchment for this stretch of coastline will be larger than any for some distance along either side. This could explain why this stretch is the most prone to slippage in the region.

It seems likely that the vast majority of the water present is being picked up by the drainage schemes.

Mole Drains cover 37% of the stretch and about 20% of water extraction. This is to be expected in that they are not going so deep down as the other scheme which they were intended to complement in key areas of particular instability. The Manholes with Moles Drains going into them are not equal in the amount, or length of moles.

# 5. SLOPE STABILITY

The degradation of natural or artificial slopes is the result of material movement which occurs chiefly owing to the action of gravitational forces. An analysis of a slopes, degradation potential can be calculated, giving identification to the extent of the slopes stability. There are various methods for analysing a slopes stability, but the appropriate method is governed by the slopes failure mode which is determined by the slopes profile, ground conditions and environment.

Section 5 examines the stability of the undercliff slope at Barton-on-Sea, through slope stability analysis indicating the potential failure mode and failure conditions.

## 5.1 Classification of Slope Failure

The movement of material on a slope can be defined under two main headings, a) mass transport and b) mass movement.

a) The movements of materials on slopes categorised as mass transport include wind-blown, rain washed and ice transported materials. This type of failure may occur simultaneously with mass movements.

b) There are several types of slope failure due to mass movement, which include creep of surface material, effects from frozen ground conditions and landslides. Mass movements, in terms of landslides, are better described as gravitational induced downward movements of discrete masses of material sliding on a single or multiple quantity of failure surfaces. The classification and characteristics of landslides is the basis for the slope stability analysis used in this report.

The type of slope slip failure is dependant on several criteria and characteristics of the stratigraphy and topographical ground conditions, where earth retaining structures can have dramatic effects on the slope stability. To establish the type of failure that will occur, careful site investigation is required, such as borehole logging, soil testing, standpipe/piezometer recording and detailed mapping of the slope and surrounding area.

## *5.2* Site Investigation: *Barton-on-Sea*

Before any stability analysis can commence a full site investigation is required. The initial investigation of a site and it's surrounding area play an important part in Geotechnical Engineering. Firstly, it is used to establish the most appropriate site for analysis, secondly to determine the most appropriate tests for that site and thirdly, establish whether these tests can be performed at that location.

The geotechnical data used for the purpose of this report, have been taken from a site investigation report compiled by Soil Mechanics Ltd (1988). Although the report by Soil Mechanics Ltd was compiled 10 years previous to this study, the data sets extracted from the report contained parameters that have no or insignificant variance over time, for example, the borehole logs, soil tests & geomorphological maps. Thus, the relevance of the data still applies, to further confirm this, previous studies of the area by Barton & Coles (1984), Curry & Wisden (1982), Melville & Freshney (1982) and Barton (1973) were also used in this study. Generally the findings matched, small discrepancies were of minor concern.

As a site investigation is beyond the scope of this study, limitations applied to where a slope stability analysis could be made. The slope stability analysis was restricted to areas where the information provided by the previous studies complemented the areas of slope instability. There have been several slip failures along the cliffs at Barton-on-Sea. However the landslides at Hoskins Gap: Grid Ref. E423700 N92900 (See Figure 4) have shown excessive activity, thus this is the area of concentration for the slope stability analysis. Further discussion on the excessive activity at Hoskins Gap is given within section 6.3. There is sufficient information produced by Soil Mechanics Ltd at Hoskins Gap for a confident representation of the geology for stability analysis.

### 5.2.1 Site & Geology: Hoskins Gap

The site of interest for the purposes of this analysis includes the cliff top and the undercliff at Hoskins Gap, Highcliff, Marine Drive, Barton-on-Sea, Hampshire, as shown in Figure 4. The cliff top is approximately 33.5m above sea level with a near vertical cliff face which extends approximately 10-12m down to the top of the slipped undercliff slope. The horizontal distance from the cliff top to the sea at low tide generally varies between 75m & 85m. The general geology of the area has a well documented profile comprising the Plateau Gravel overlying Upper and Middle Barton Beds. The geological data from selected boreholes, Halcrow (1987), on the cliff top enabled identification and location of the major strata. The boreholes used for the slope stability analysis are as follows and are shown in Figure 19.

Borehole **1** - E423753 N92985
Borehole **2** - E423748 N92935
Borehole **4** - E423748 N92923
Borehole **5** - E423729 N92927

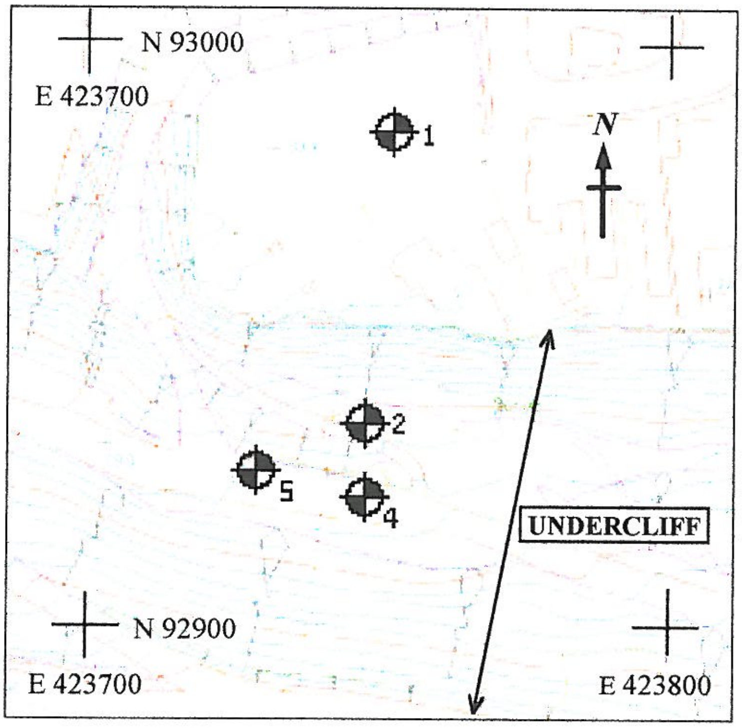


***Figure 19 - Contour map of location of boreholes used in stability analysis.***

However, the boreholes located within the undercliff, although giving clear results at that location, will not enable reliable identification of surrounding strata.

The failure history of this area over the past years together with the remedial work, which was mostly performed unrecorded, gives doubt to the consistency of the undercliff geology, i.e. where there are unidentified pockets of material. Despite this, the undercliff boreholes can be used confidently to identify slip planes which in-turn can be used to distinguish pre-existing slip surfaces.

The long term stability of slopes is governed by the strength of the soil in first time slides. In pre-existing slip surfaces the long term stability will be governed by the residual strength of the soil, (in turn a function of pore pressure). Therefore it is of utmost importance to identify pre-existing slip surfaces enabling the correct soil parameter to be applied.

For simplicity the slip material within the undercliff has been divided up into two strata, a thin top layer of medium dense gravel overlaying a variably thick layer of soft sandy silt. The soil properties of these assumed layers, such as the strength parameters have been approximated from the resultant tests on the borehole samples. A cross-section of the slope profile is shown in Figure 20, the topographical dimensions were taken from a 1m contour plan surveyed and produced by Rendel Geotechnics for NFDC. The slip surface co-ordinates shown in Figure 20 have been generated from strata depth approximations given by the boreholes and the knowledge of the slip plane created by the Chama Bed. The "F" slip surface in the Middle Barton Clay, as discussed by Barton (1973) and Barton & Coles (1984), prompted the front slip as shown in Figure 20. Based on the system for the classification of landslides according to the shape of the landslide mass by Skempton & Hutchinson (1969), the slope failure at Barton-on-Sea is classed as a compound rotational non-circular slip. Non-circular slips are types of mass movement that are distinguished as a rotational slide. Rotational slides occur characteristically in slopes of fairly uniform clay or shale. The characteristics of non-circular slips are further discussed in section 6.4.

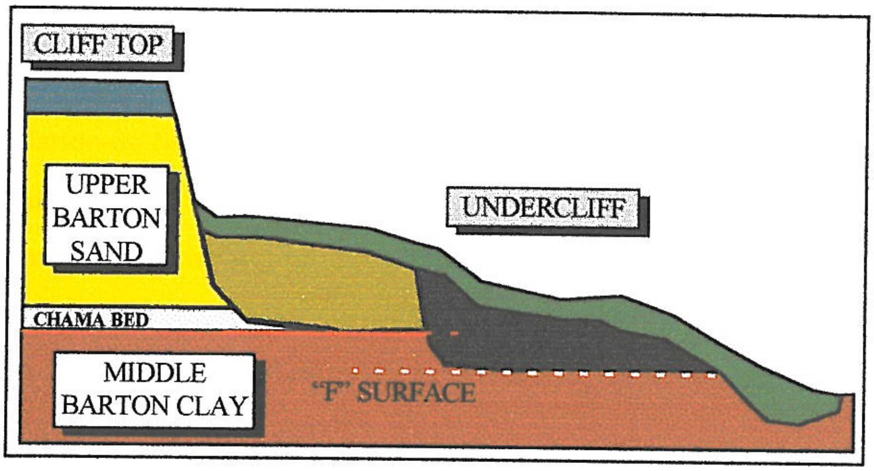


***Figure 20 - Cross-section indicating the presumed profile of undercliff pre-existing slippage. Note: Not to scale.***

### 5.3 Slope Stability Analysis

The main concerns in a slope stability analysis are firstly, to ascertain the particular characterisation of the soil layers actually present in the slope and secondly, to establish accurate estimation of the pore water pressure. The latter data obtained was not sufficient for accurate analysis, however the pore water pressure has been dealt with, as explained in the next section.

### 5.3.1 Effects of Soil Parameters on Analysis

The geology of the slope has been identified through the site investigation, yet before any slope stability analysis technique can be applied, several parameters have to be rearranged into a usable form. In order to calculate the pore pressures on a slip surface, information regarding the pore pressure distribution throughout the soil mass is required. The pore pressure distribution can be defined by the position of the water table with the aid of flownet diagrams. However, in the absence of sufficiently detailed information about the slope's water table, the alternative method of using an average pore pressure ratio ($R_u$) has been adopted for the purposes of analysis.

To calculate the total stresses in saturated clay, i.e. $\phi = 0$, the pore water pressure nor a pore pressure ratio are required. Whereas the pore pressure ratio, $r_u$ concept is applicable in strata where the shear strength is dependent on pore pressure, i.e. where shear strength ($\phi$) is greater than zero as in effective stress analysis. All strata tested at the Barton-on-Sea site have shown $\phi$ greater than zero. It is recognised that excavations and regrading alters the pore pressure and although the slopes at Barton-on-Sea have experienced both of these events several times, consideration of these pore pressure changes is far too complex to consider in this analysis. As stated previous, the slipped zone which includes the excavated and regraded material has been simplified into two layers.

The effects of soil suction considered as negative pore water pressure, are insignificant and will be ignored in the slope stability analysis.

The slope under question extends down to the shore line and the sea level has been taken at low spring tide, where wave conditions apply. Again, for non-complexity, the portions of the water surfaces outside the slope, in front and behind, have been considered horizontal, i.e. similar to static conditions.

## 5.4 Non-circular slips

The cliff face at Barton-on-Sea cannot be idealised as having either long or uniform slopes, therefore cannot be analysed as an infinite slope. This technique, as discussed by Skempton (1964), can be dismissed for the analysis of the Barton-on-Sea cliffs as the effects of external loads and surcharges are not taken into account. However, realistic analysis for the stability of the cliffs may still be investigated by considering any localised destabilising effects at the top and/or bottom of the cliff. It is also necessary to establish the variation in the slope gradient and ground conditions, where the infinite slope method is insufficiently detailed. Inclusion of these extra factors into the slope stability analysis provides a more general technique which can be applied to all slope conditions.

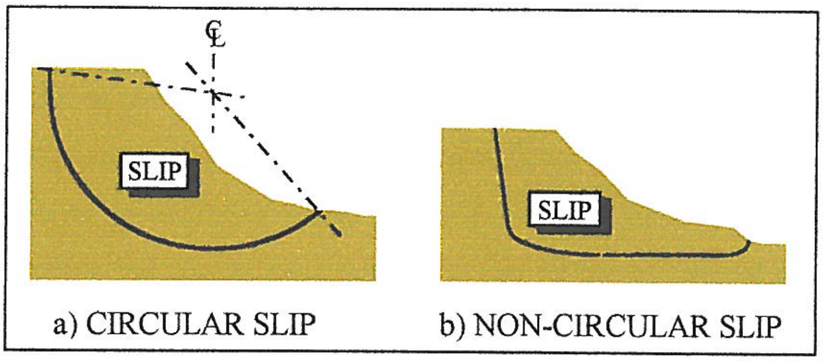


***Figure 21*** *- Typical profiles of a) Circular and b) Non-Circular slope slips.*

Circular and non-circular slip surfaces can be analysed for any slope but non-circular slips can be assumed where there are reasonably well defined pre-existing planes of weakness, as identified in the cliffs at Barton-on-Sea.

A method of analysis for non-circular slips can be based on Fellenius' (1927) conventional "Swedish Method of Slices", where the slope under question is divided up into slices of known dimensions and properties. By assuming the resultant interslice forces as zero the Factor of Safety (*FOS*) can be obtained by resolving forces parallel to the slip surface for each slice. Hence a slope with a non-circular slip can be divided up into slices similar to that shown in Figure 22. The method works for non-circular slopes because the errors in its assumption of zero interslice forces tends to cancel out the errors from its application due to departures from circularity.

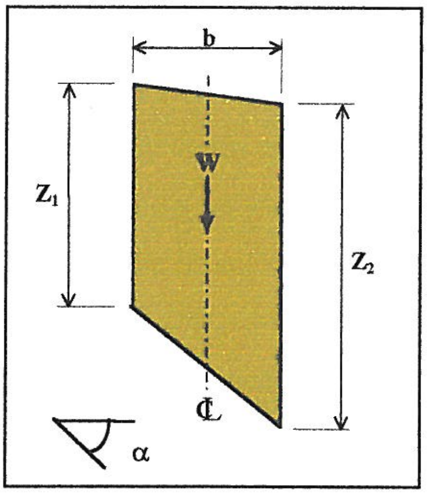


***Figure 22*** *- Typical slice section for slip analysis indicating dimension required.*

### 5.4.1 Janbu's Method: Interslice Forces

This method developed by Janbu et al. (1956) and furthered by Janbu (1973), can be applied to both circular and non-circular slip surfaces. It is a method suitable for general routine use by resolving the horizontal and vertical forces acting on each slice and assuming that the resultant of the forces act in the horizontal direction. The equation for the semi-rigorous method of Janbu can be written as;

$$FOS = f_o \frac{\sum\left[\left(c'b + (W - ub)\tan\phi'\right)\left[\frac{1+\tan^2\alpha}{1+\tan\alpha\tan\phi'/f}\right]\right]}{\sum\left[W\tan\alpha\right]}$$

Where;

$W$ = Weight of the soil mass
$c'$ = Compressive Strength
$b$ = Width of section slice
$f$ = Initial estimation for $FOS$
$u$ = Pore Pressure
$\phi'$ = Strength of Soil
$\alpha$ = Angle of section
$f_0$ = Correction Factor

The equation shown above considers the pore pressure ($u$) acting within the slope, the equation can be re-written incorporating $r_u$ rather than $u$, thus the equation becomes;

$$FOS = f_o \frac{\sum\left[\left(c'b + (1 - r_u)\tan\phi'\right)\left[\frac{1+\tan^2\alpha}{1+\tan\alpha\tan\phi'/f}\right]\right]}{\sum\left[W\tan\alpha\right]}$$

This solution is more convenient to solve than Janbu's rigorous method which satisfies the equilibrium criteria as originally indicated by Janbu. The discrepancy between the two methods is developed through the following assumption used in the semi-rigorous method. The assumed force distribution satisfies the overall vertical and horizontal equilibrium but not the moment equilibrium. This leads to errors in the calculated factor of safety. Although the errors are on the safe side, they can be in the order of 15%. This potential misleading result can be excessive and thus not acceptable for Factor of Safety approximations. It was found that the errors increased according to the ratio of depth to length of the slipped mass, giving large errors for deep slips. Using a correction factor ($f_o$) related to the depth/length ratio of the slip which has been deduced from the solutions of the rigorous method gives a satisfactory Factor of Safety. Thus the true Factor of Safety using the semi-rigorous method is calculated by multiplying each iteration by the correction factor. Hence, the introduction of $f_o$ equates to give the following;

$$FOS_{(True)} = f_o * f_{(calc)}$$

The values of $f_o$ are taken from a graph of $f_o$ plotted against the ratio d/L where the correction factor is a function of the d/L ratio, curvature ratio (the slip shape) and the soil condition & type. The graph of $f_o$ against d/L is shown in Appendix B.

It is this equation (Janbu's semi-rigorous) that has been used for the slope stability analysis of the cliffs at Barton-on-Sea.

### 5.5 Slope stability Analysis: Barton-on-Sea

On consideration of the geology of the cliffs and slopes at Barton-on-sea, as shown by the cross-section in Figure 20, a cross-section slip surface could be identified. Considering all the points mentioned in the previous sections, it was concluded that two failure slip planes were feasible, as indicated in Figure 23.

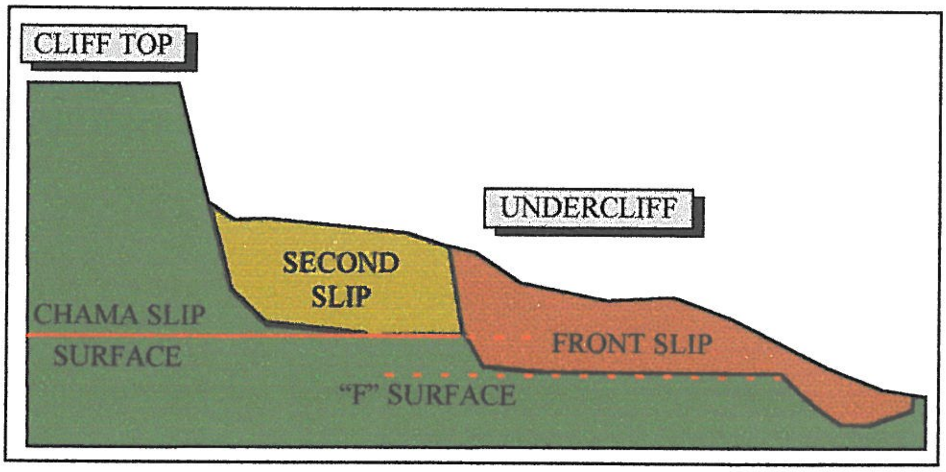


*Figure 23 - Proposed slip profile through undercliff, Note not to scale.*

The location of the cross-section was determined by the boreholes discussed in section 6.2.1 and shown in Figure 19. The Ordnance Survey grid reference coordinates for the ends of the cross-section are;

| | | |
|---|---|---|
| Landward End | - E 423753 | N 92985 |
| Seaward End | - E 423741 | N 92862 |

and a location plan of the cross-section is given in Figure 24.

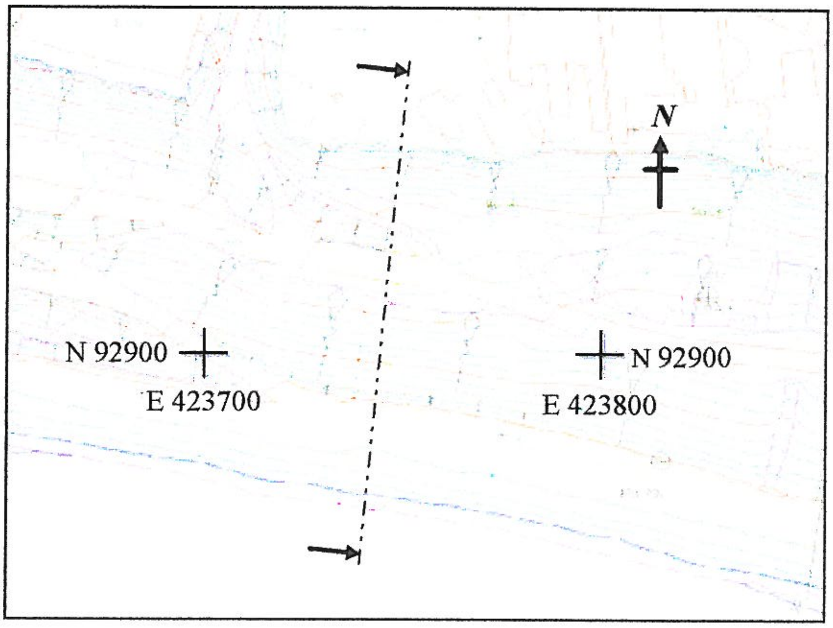


*Figure 24 - Location plan of cross-section used for stability analysis.*

The two failure slips considered are;

1) Front Mass Slip

2) Entire Slope Slip

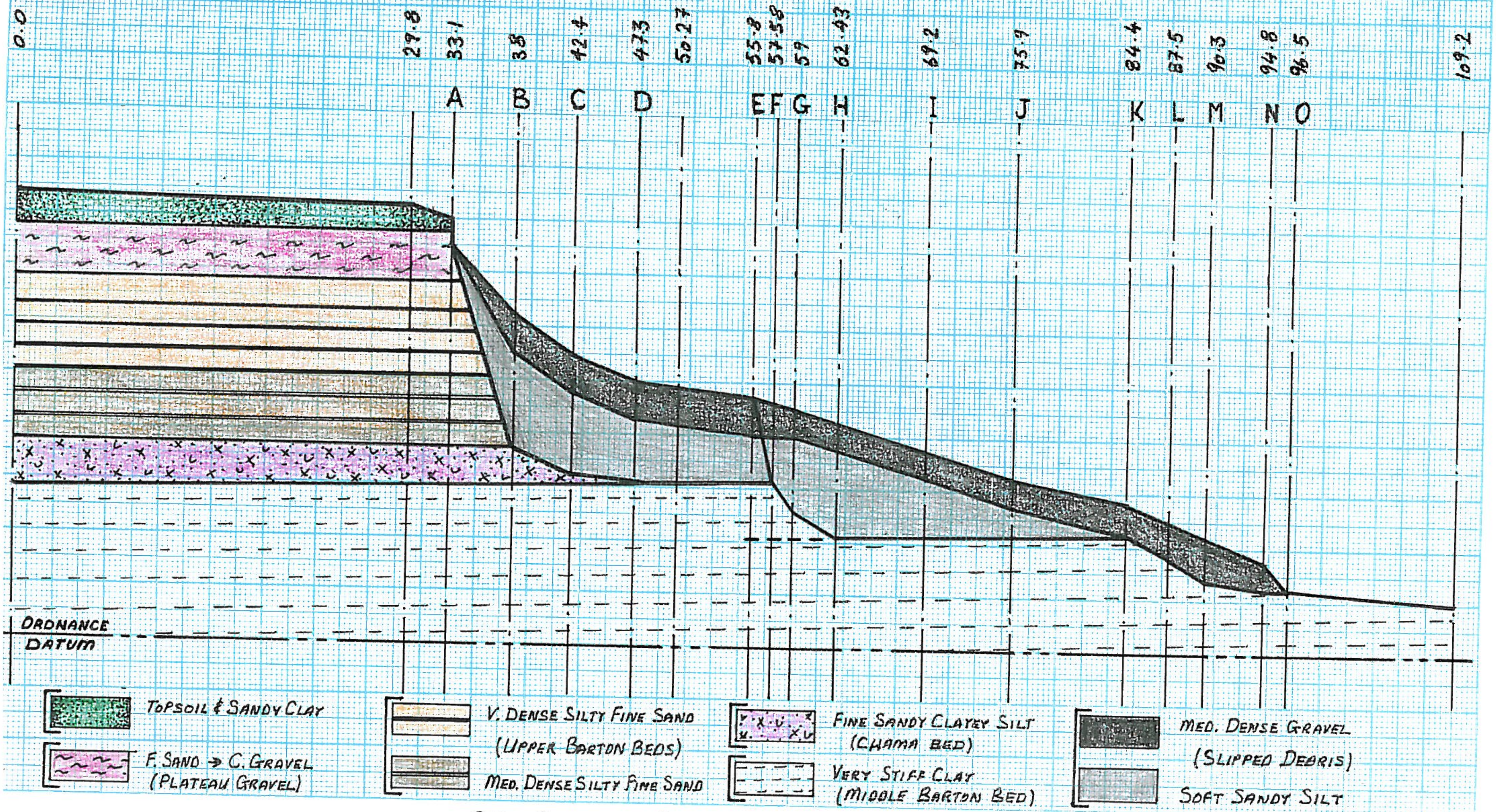
The first slip surface examined considers that the front slope shall slip on the weaker "F" plane in the Middle Barton Clay. As this fails the upper potential slip mass resting on the Chama Bed slides downwards. This is considered as a secondary slip as it is dependent on the first slip occurring. The second slip surface identified considers the entire slope as a single entity, i.e. failure in one slip. The reasoning behind this theory was invoked by the fact that the slope has two pre-existing slip surfaces, the Chama bed and the "F" plane. The occurrence of either failure slip results in the total failure of the slope. The purpose of distinguishing between the two failure modes will help in the understanding of the slopes stability, i.e. the analysis shall give each failure mode a Factor of Safety. The more analysis of failure modes the better the understanding for slip prediction. However in this case the failure modes are straight forward, the pre-existing slip surfaces have significant influence on the slopes stability.

Once the slip surface(s) have been clarified, the methodology of Janbu's interslice stability analysis may commence. A cross-section profile of the cliff at Hoskins Gap is shown in Figure 25 and the breakdown of both slips into slices for the analysis is given in Appendix B.

Since the Pore Pressures within the slope were unknown, the incorporation of an average Pore Pressure ratio, $R_u$,, was used. The slope at Barton-on-Sea is not likely to sustain a high level of saturation without failure, due to its strata configuration and the manner that the two top layers have been placed in past remedial measures. It is believed that a maximum average pore pressure distribution ratio of 0.5 is achievable, the analysis will determine whether the cliff will fail before this value is reached.

Usually when the average pore pressure ratio, within a slope, reaches 0.5 it is rendered unsafe and extreme values greater than 0.5 seem highly unlikely. It is considered as the authors approximation, prior to analysis, that an average pore pressure ratio within the Barton-on-Sea slope would be around 0.50, possibly less. To validate the analysis, the two failure modes were analysed over a range of $R_u$ values, from 0.20 to 0.60 in 0.05 intervals. This would enable a graph of the ratio $R_u$ against the Factor of Safety (*FOS*) to be plotted and would be unique to that cross-section at Barton-on-Sea.

In the analysis of the slope stability, various values of $\phi'$, ranging from 12° to 18° & 24° specific to the Chama Bed and the "F" plane were used. This was done as an exercise to test the sensitivity of the slope and was applied to both failure modes. The values of $\phi'$ specific to the remainder of the slip surface remained constant throughout the analysis.



CROSS-SECTION OF CLIFF AT HOSKINS GAP FOR INTERSLICE ANALYSIS

FIGURE 25

### 5.5.1 Results of Analysis

As expected, there is a linear relationship between *FOS* & $R_u$ and that increasing $\phi$' will increase the *FOS* for a given value of $R_u$. The extent and sensitivity of the slope section taken at Barton-on-Sea has interesting findings which requires discussion and decisions on future remedial measures to be taken.

**Failure Mode 1)** Front Mass Slip

The computation of Janbu's slope stability theory for failure mode 1 is presented in Appendix B, where the findings are summarised as a graph in Figure 26.

The effects of $R_u$ on the *FOS* for the front slope slip are very influential where the factor of safety alters in approximate steps of 0.25 if the $R_u$ ratio changes by 0.1. For example, if $R_u$ is equal to 0.2 then *FOS* equals 1.25, if $R_u$ increases to 0.3 then *FOS* reduces to 1.0, the point at which the slope will fail. Conversely, if $R_u$ decreases the *FOS* increases with the same proportionality as Figure 26 implies.

The front slope slip ceases to be stable, i.e. *FOS* is less than 1.0, between a pore pressure ratio range of 0.32 and 0.53 when $\phi$' is equal to 12° and 24° respectively. It is clear that the failure of the front slope is adversely effected by the change in angle of shear resistance, $\phi$'. This can be explained by discussion of the procedure of the interslice method of analysis. The front slope was divided up into ten interslices where the preferred slip plane, the "F" surface, corresponded to approximately 22m from a total slip surface of 45.5m. Thus the "F" surface of the front slip contributed to 48.5% of the slip surface. Therefore by changing the value of $\phi$' for the "F" surface will have dramatic affects on the *FOS* with respect to the pore pressure distribution.

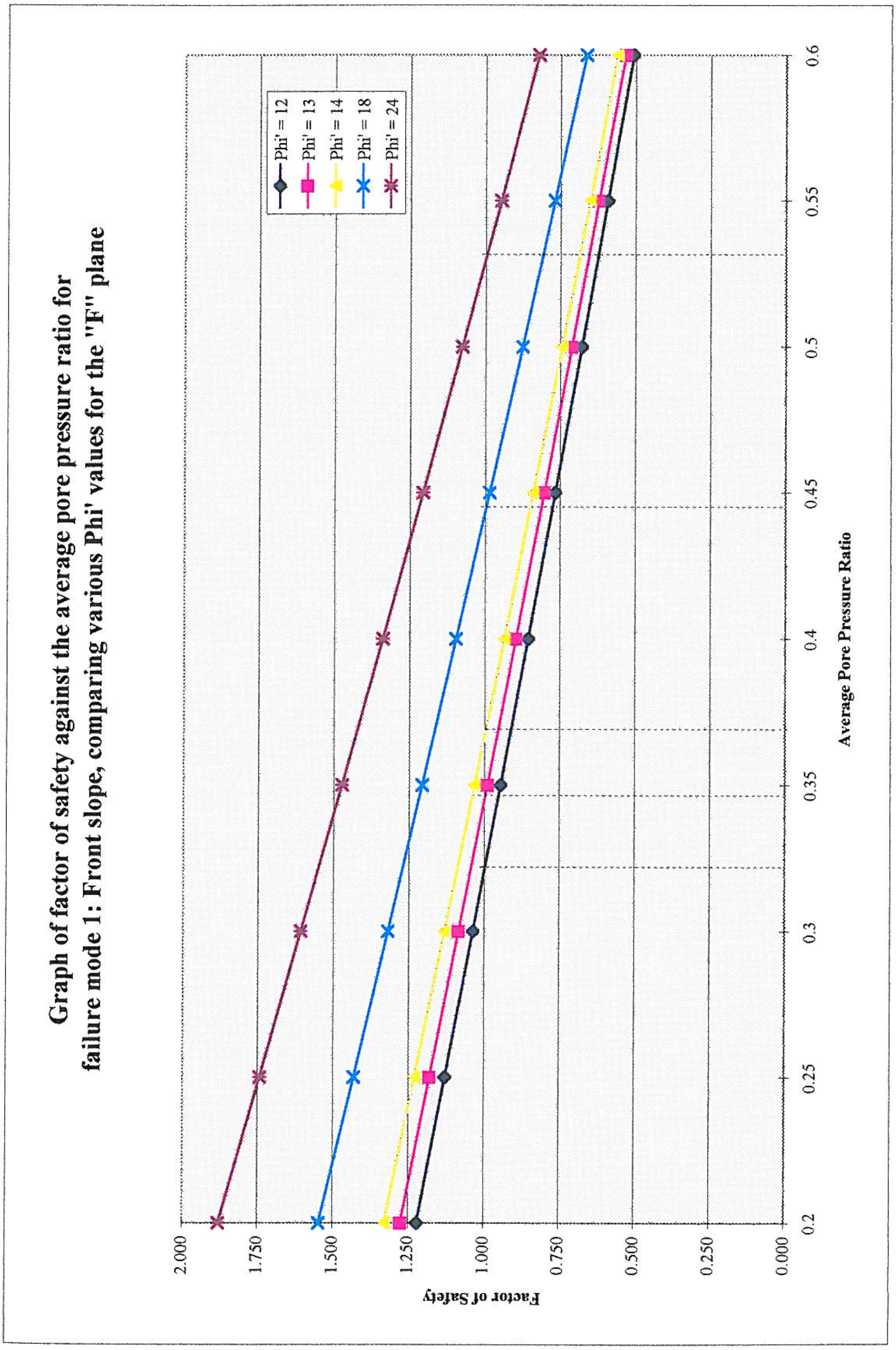


*Figure 26 - Graph of Failure Mode 1: Front Slope.*

**Failure Mode 2)** Entire Slope Slip

The computation of Janbu's slope stability theory for failure mode 2 is presented in Appendix B, where the findings are summarised in Figure 27. Figure 27 is a graph of $R_u$ plotted against *FOS*, the Factor of Safety of the entire slope failure.

The correlation between the *FOS* and $R_u$ for the entire slope failure is as follows; an 0.1 interval of $R_u$ relates to an approximate *FOS* change of 0.2, again this relationship is dependant on the $\phi'$ used for the Chama Bed & "F" slip planes.

As shown on Figure 27, $R_u$ varies from 0.34 to 0.47 for $\phi'$ equal to 12° and 24° respectively when the *FOS* equals 1. This difference in $R_u$ is mildly significant to the sensitivity of the slope in terms of the soil strength parameter $\phi'$. In the interslice analysis for the entire slope, fourteen slices were taken representing approximately 80m of preferred slip surface. 10.3m corresponded to the Chama Bed slip surface and 22m lay on the "F" surface, totalling approximately 32.3m, equivalent to 40% of the total slip surface.

The sensitivity of the entire slope failure is less dependant on the variant of $\phi'$ as discussed in the last section for the front slope. This is due to the reduced percentage of variable $\phi'$ slip surface length, which is made up of the Chama Bed and the "F" plane.

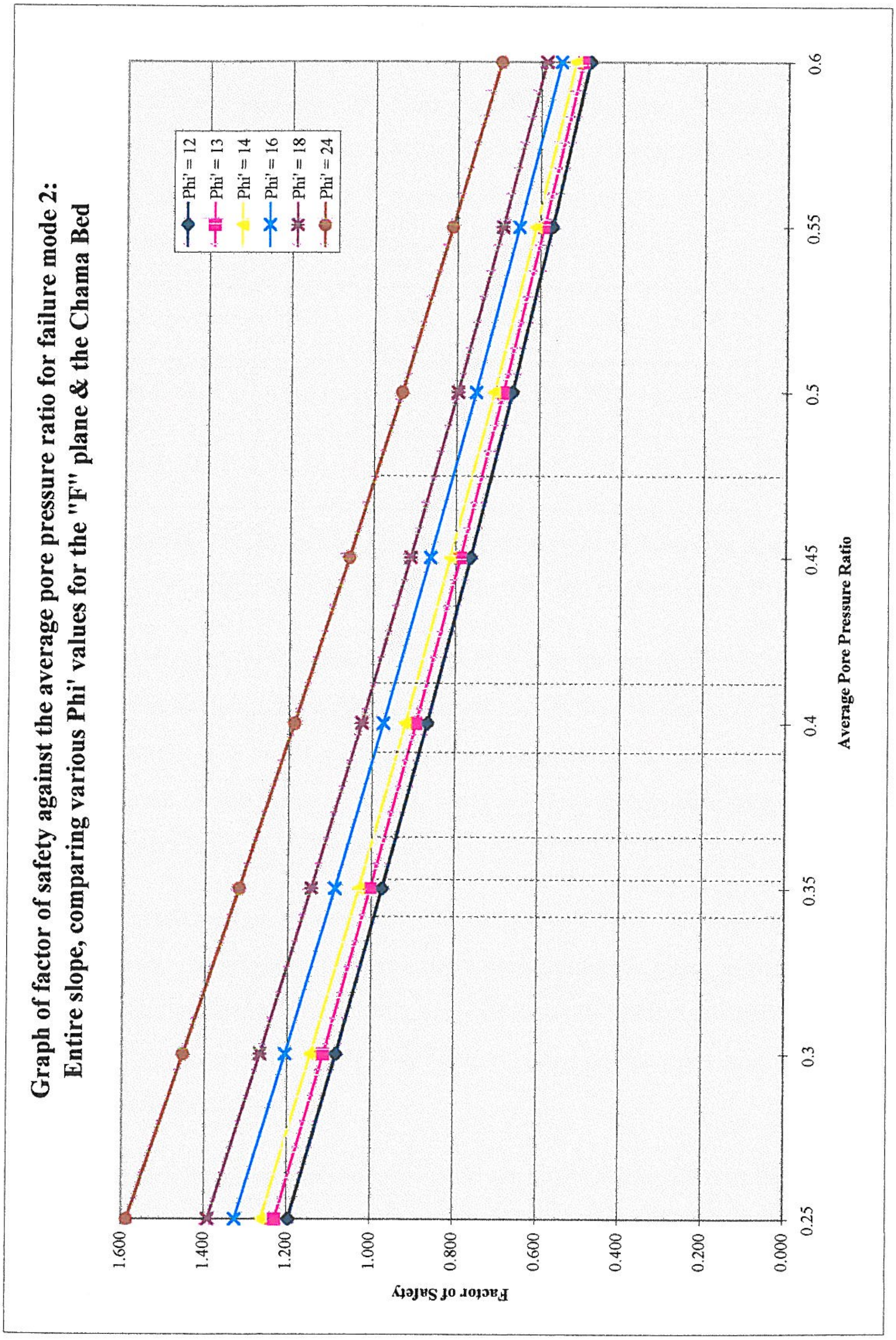


*Figure 27 - Graph of Failure Mode 2: Entire Slope.*

### 5.5.2 Comparison of Entire & Front slip failure

The effects of changing $\phi'$ to test the sensitivity of the slopes stability, can be used to generalize the type and profile of the slopes at Barton-on-Sea. The results of the analysis, in terms of $\phi'$ and $R_u$, when compared are similar, but the front slope failure has a noticeably wider dispersion of $R_u$ in relation to the change in $\phi'$. The results for the comparison are summarised in Table 5.

| | 12° | 13° | 14° | 18° | 24° |
|---|---|---|---|---|---|
| **FRONT SLIP** | 0.32 | 0.34 | 0.37 | 0.44 | 0.53 |
| **ENTIRE SLIP** | 0.34 | 0.35 | 0.36 | 0.41 | 0.47 |

***Table 5 - Comparison of $R_u$ for the Front and Entire slope failure with $\phi'$ equal to 12,13,14,18 & 24° within the Chama Bed & the "F" slip surfaces for a FOS = 1.***

This difference effected by the changing of $\phi'$ is due to the percentage of preferred slip surface to the total slipped surface length of each failure mode, as explained in the previous section. The significance of minor changes of $\phi'$ in either failure mode has some influence on the factor of safety, but it is the change in pore pressure that controls the slopes *FOS*.

The realistic fluctuations of $\phi'$ along the Chama bed or on the "F" plane are most probably small and can be generalised as a unity figure along the plane, as utilised for the calculation in this report. The results, as summarised in Table 5, suggest that the analysis can be confident with its *FOS* predictions once an appropriate $\phi'$ value is given for the preferred slip surfaces.

The confidence lies in relating this slope section taken at Hoskins Gap to the rest of the cliff section at Barton-on-Sea. There is enough confidence to suggest that the entire cliff will act similar to that identified through this slope stability analysis.

The effects of pore pressure distributions for each failure mode, as noted before, give different gradients for the linear relationship between $R_u$ and $\phi$'. The relationship between the front slope slip and the Entire slope slip is different for each value of $\phi$'. This can be seen in Figure 28, Figure 29, Figure 30 & Figure 31 for $\phi$' equals 12°,14°,18° & 24° respectively.

These graphs represent, whether the slopes at Barton-on-Sea shall fail as an entire slope or if the front slope will fail first. Although the failure through either mode will result in total slope failure, the knowledge of which mode of failure will affect the measure of remedial work. Stabilising the front slope will prove considerably less costly than stabilising the entire slope.

Figure 28, comparison of entire slope with front slope stability for $\phi$' equals 12°, shows that the intersection of the two lines lies below the critical *FOS* of 1.0. The significance of any values below this threshold of FOS as 1.0 should be ignored as it represents that the slope has failed. The severity of failure is not required as no useful gain can be made from this information, except in relating a present failure position to a desired *FOS*. Figure 28 implies that if the preferred slip surfaces contained an angle of shear resistance of 12° then the slope would fail initially by the front slip followed by the rest of the slope when $R_u$ exceeds 0.31. This same result would occur in the slope for values of $\phi$' up to and including 14°, as shown in Figure 29, where the intersection of the two lines lies directly where the *FOS* equals 1.

Obviously, for $\phi$' greater than 14° the results indicate that the slope will fail as an entire slope slip, as shown in Figure 30 & Figure 31 for $\phi$' equal to 18° & 24° respectively. The intersection of the two lines lie well above the *FOS* threshold of 1.0, in fact they do not intersect until the slope is practically displaying arid conditions, i.e. when $R_u$ is around 0.1 - 0.05 which is a highly unlikely state for a coastal cliff.

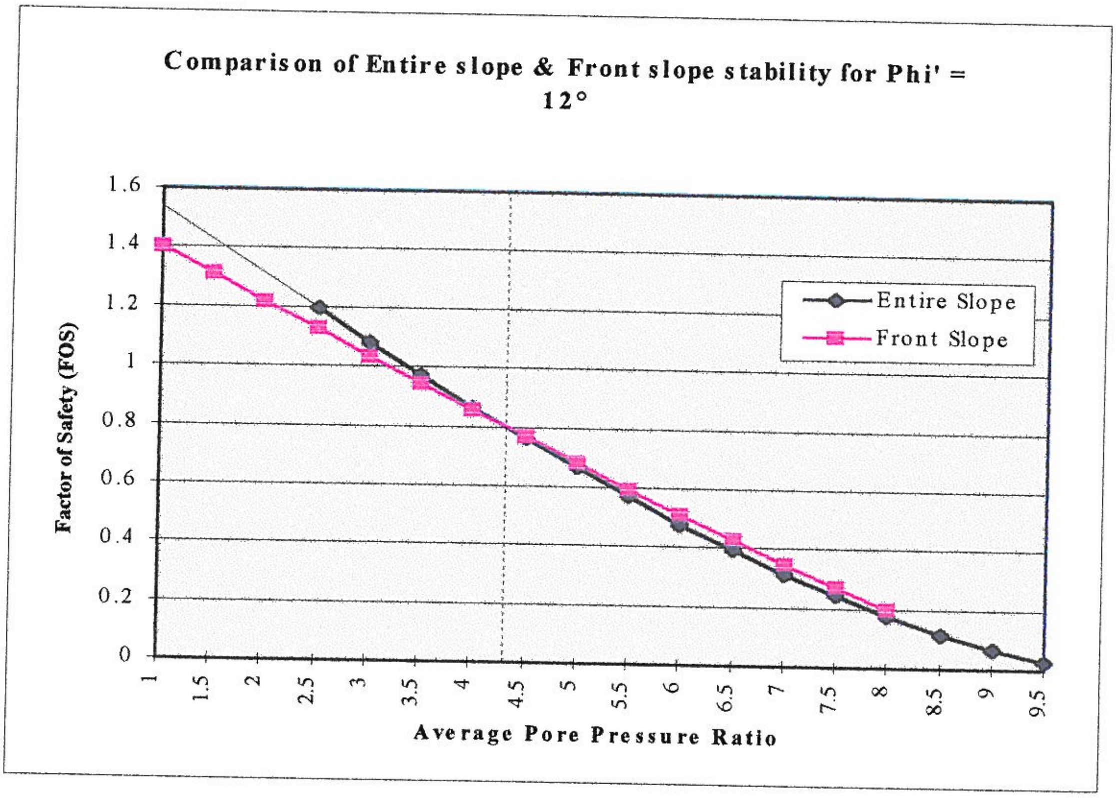


*Figure 28 - Comparison of Front Slip & Entire Slip for Phi' = 12°.*

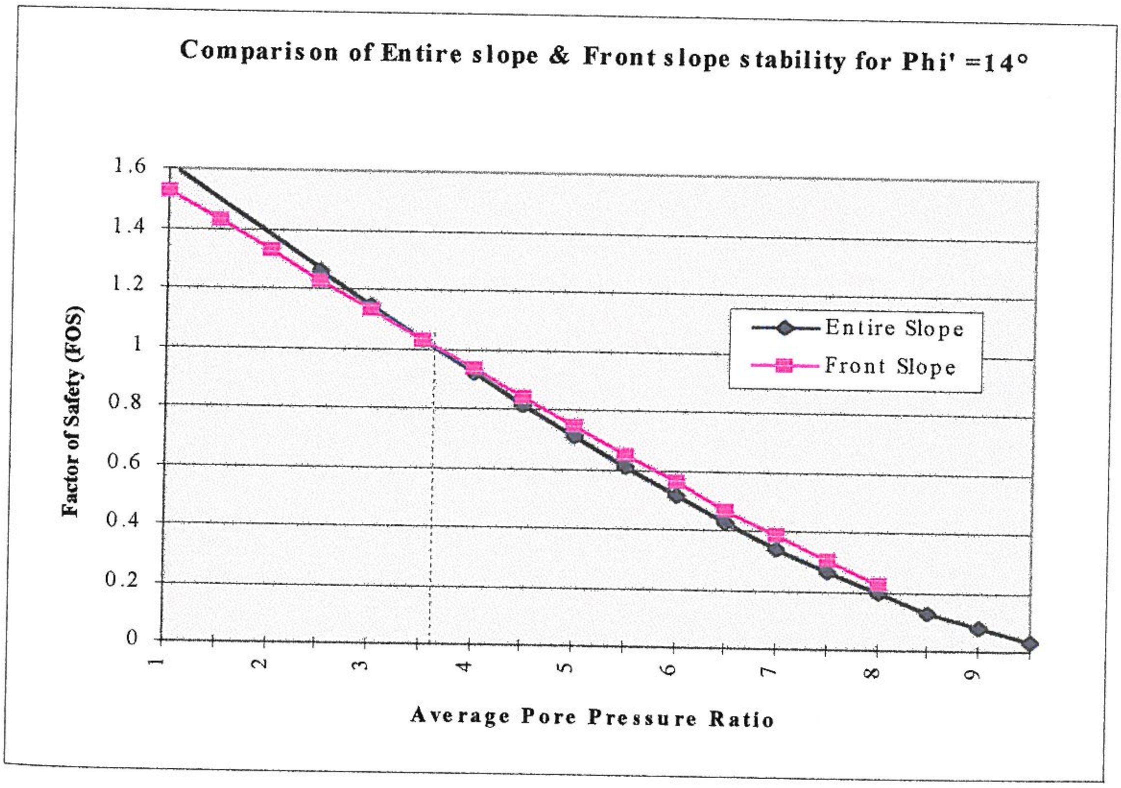


*Figure 29 - Comparison of Front Slip & Entire Slip for Phi' = 14°.*

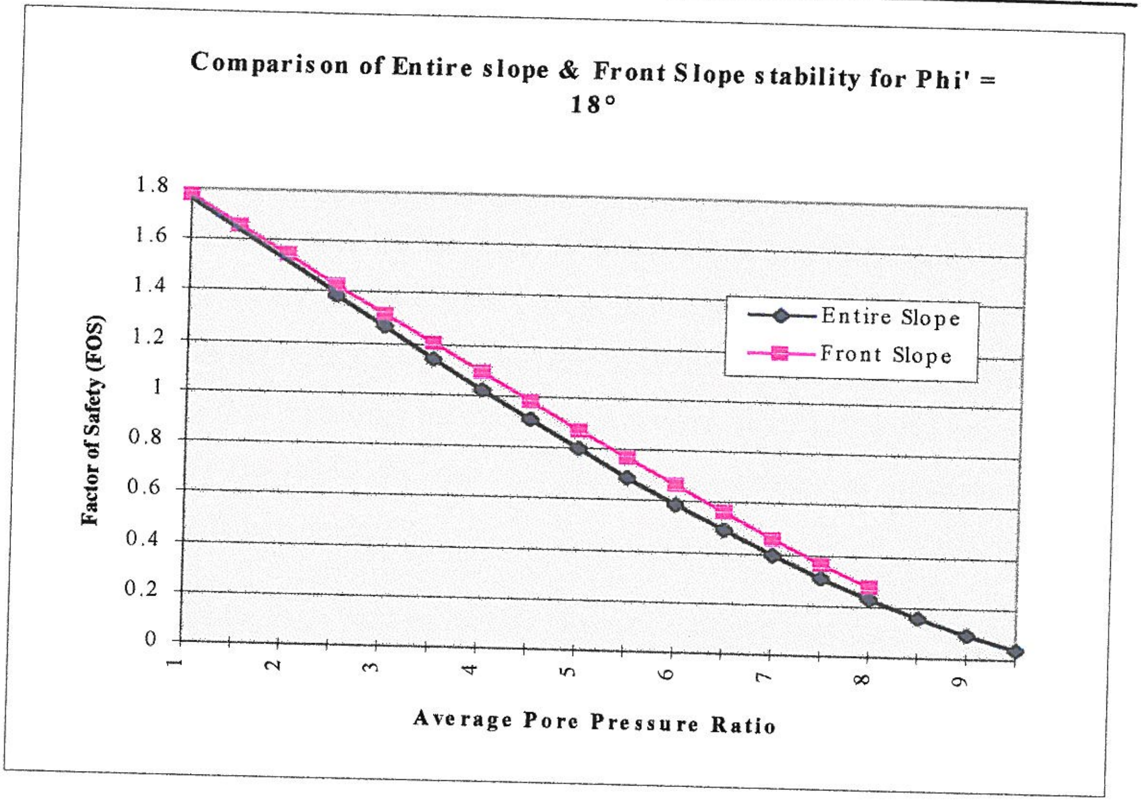


*Figure 30 - Comparison of Front Slip & Entire Slip for Phi' = 18°.*

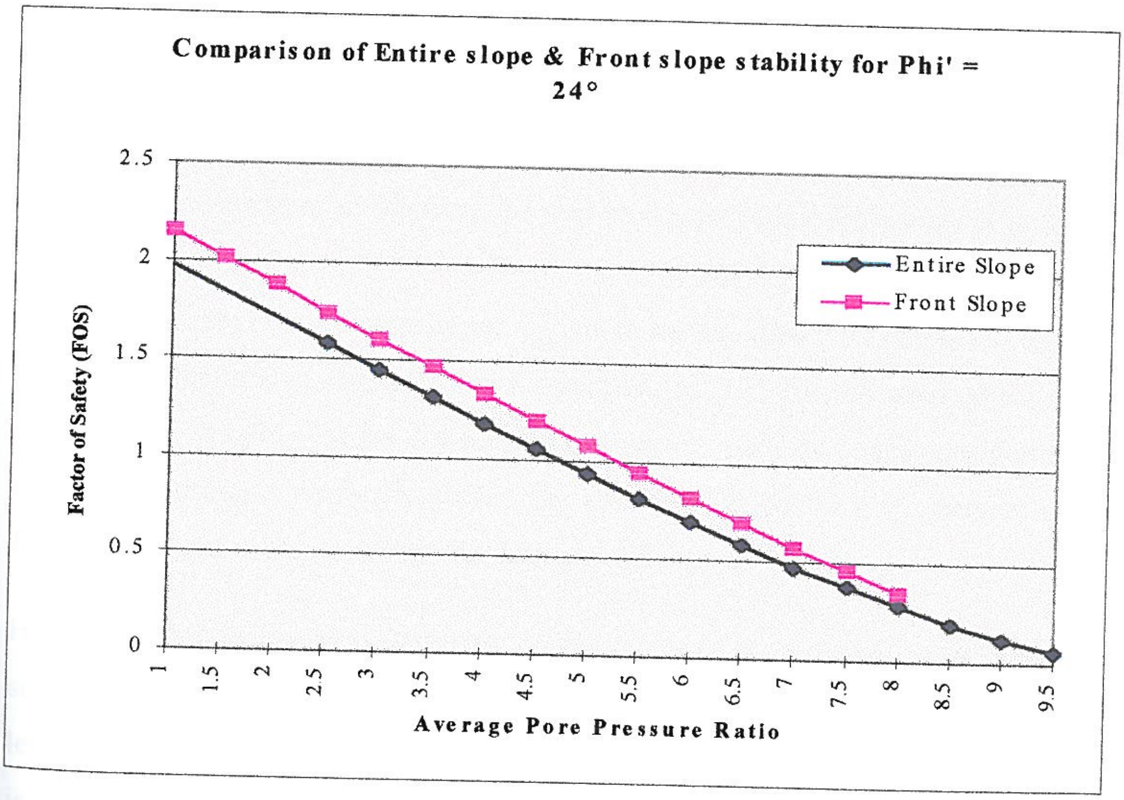


*Figure 31 - Comparison of Front Slip & Entire Slip for Phi' = 24°.*

### 5.5.3 Significance of Results

The slope failure mode is dependent on the values of $\phi$' of the slip plane(s). It has been suggested that failure mode 1, a front slip, applies when $\phi$' is equal to or less than 14° and values above 14° correlate to failure mode 2, an entire slope slip. The exact value for $\phi$' to be used for the Chama Bed and the "F" plane requires further investigation as the references available and used for this analysis do not agree on a singular value. The difference between the texts varies from 12° to 18° and as Figure 28, Figure 29, Figure 30 & Figure 31 show, this variance is significant to the prediction of a failure mode.

The majority of the texts studied for this analysis indicated that the $\phi$' for the Chama Bed is more inclined to the higher value of 18°, the certainty of this value is low. However, a value has to be applied for this analysis to be relevant to the stabilising of the undercliff slopes at Barton-on-Sea. Thus, it is accepted, for the purposes of this report, that the value of $\phi$' equals 18° for the Chama Bed and the "F" plane. This implies that the undercliff slope section at Barton-on-Sea will fail as an entire slip when an $R_u$ value of 0.41 is reached.

This $R_u$ value of 0.41 is not a desirable condition as it lies on the critical *FOS* of 1.0, a recommended condition as stated in the current design codes, for a slope is to have a *FOS* of 1.2 or 1.5 if possible. For a *FOS* of at least 1.2, Figure 30 for $\phi$' equal to 18° indicates that the pore pressure ratio, $R_u$, has to be less than 0.32 and 0.20 for a 1.5 *FOS*. It is realistic to restrict $R_u$ to a minimum of 0.25 for this area of coastline, where it may possibly reduce down to 0.2 in very dry periods. Thus considering the minimum consistent yearly $R_u$, within the undercliff to be 0.25, the corresponding *FOS* equals 1.38, which is within the desired safety range.

However, when focusing on the yearly winter values of $R_u$, a realistic estimate would suggest around 0.55 as a maximum value, with around 0.5 as a normal annual winter level. Figure N clearly shows that the slope will fail when $R_u$ reaches 0.41, this value is well below the estimated maximum value and the annual winter level. This suggests that the slope will fail during the wet seasons even in those which are not necessarily of adverse conditions.

The above statement suggests that the slopes at Barton-on-Sea will probably fail annually as an entire slope during each wet season. This is not the case in reality, the last major slip occurred four and a half years before this study. This stability can be explained by the land drainage installed in the undercliff removing groundwater and thus reducing the pore pressures within the undercliff. It seems that these land drains can cope with removing enough groundwater to keep the cliff stabile in normal wet season conditions. In excessive condition, as experienced in the winter of 1993, the slopes will fail and they have.

## 5.6 Worked Example of Stability Analysis: Barton-on-Sea

The actual groundwater conditions within the slope at Barton-on-Sea are unknown. This missing factor/information affects the significance and relevance of the slope stability analysis and is crucial in assessing the true behaviour of the slope.

Although the groundwater information within the undercliff is unattainable an approximation of the groundwater profile can be made and than converted into pore pressures. This estimation of the pore pressures can be further exploited to enable an approximation to be made on the efficiency of the drainage systems located in the undercliff.

### 5.6.1 Treatment of Pore Pressures in Slopes

An approximation of the groundwater conditions within the undercliff can be estimated if a known groundwater level within the cliff is specified. By estimating the groundwater level within the undercliff during a wet season a comparison to the potential value of $R_u$ can be made. This comparison will provide an estimate of the efficiency of the drainage systems within the undercliff.

This can be achieved by producing a flownet for the slope and establishing the groundwater profile. The flownet of groundwater can then be converted into values of $r_{ui}$ at nodal points on a grid produced over the flownet.

Where;

$$r_{ui} = \frac{U}{\gamma h}$$

$U$ = Pore Water Pressure

$\gamma$ = Bulk Density of Soil

$h$ = Depth from G.L.

The values of $r_{ui}$ can be contoured and divided into $n$ equal width areas, for each area the $r_{ui}$ values can be averaged to give an average pore pressure ratio, $R_u$, where for each slice area;

$$r_u = \frac{\Sigma h_i \, r_{ui}}{\Sigma h_i}$$ when $\Sigma$ are $\sum_{1}^{i}$ in both cases

$i$ = The number of pore pressure zones in each area.

Once each slice area has been averaged an overall average for the slope can be given by;

$$R_u = \frac{\Sigma A_n \, r_{u_n}}{\Sigma A_n}$$ when $\Sigma$ equals $\sum_{1}^{n}$ in both cases

Where; $A_n$ = Number of equal areas.

$r_{un}$ = Number of average $r_u$'s for each area.

### 5.6.2 Estimation of the Pore Pressures: Barton-on-Sea

The procedure explained in section 6.6.1 for estimating average pore pressures can be applied to the undercliff slopes at Barton-on-Sea. An initial groundwater level established far back into the cliff top will enable a flownet of the undercliff to be produced on the bases of a few investigated assumptions. Before these assumptions are discussed, it is appropriate to deliberate why the groundwater profile used by Robert West & Partners (1991), for their analysis of cliff stability of the Barton area on behalf of NFDC, is not utilised in this estimation.

Figure 32 is an approximate (not to scale) representation of the groundwater profile used by Robert West & Partners (1991) for their analysis of cliff stability at Hoskins Gap, Barton-on-Sea. It is clearly shown that the groundwater profile, indicated by the dark blue line in Figure 32, penetrates the Chama Bed and passes through the Middle Barton Clay. The profile shown does not represent the adverse affects of the pore pressure differences between the Upper Barton Sand and the Middle Barton Clay.

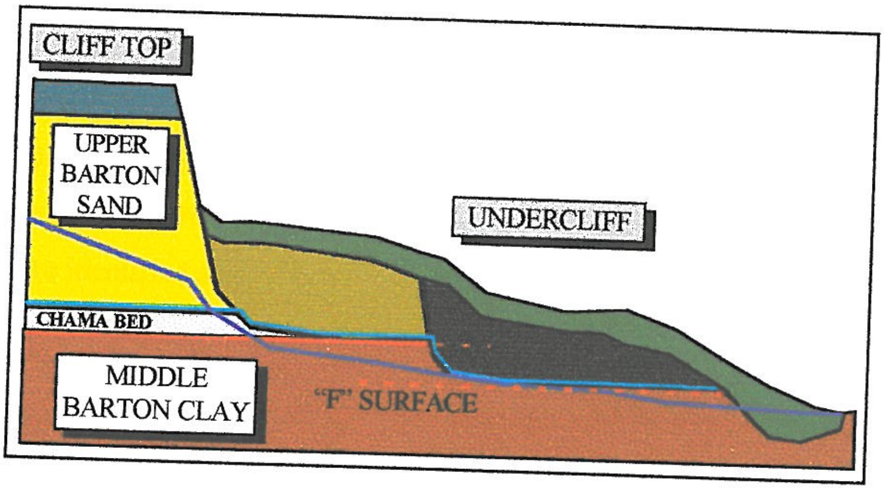


***Figure 32- Cross-section of cliff and undercliff indicating G.W. levels produced by R. West & Partners(1991) and the newly determined boundary flowline.***

The Middle Barton Clay would restrict the flow of groundwater to within the Upper Barton Sand creating a bounding flowline along the length of the clay layer. Although some groundwater will percolate into the clay, i.e. acting as a leaky aquifer, it can be safely assumed that the top undercliff section will act similar to an unconfined aquifer. The identification of the "F" slip plane within the Middle Barton Clay will further help develop a more realistic profile of the groundwater conditions. Robert West & Partners report to NFDC does not recognise or acknowledge the presence of the "F" plane in its stability analysis.

The "F" plane has been considered to be responsible, along with the Chama Bed surface, for the potential failures of the slope. Therefore, the intersection within the colluvium between the Chama Bed & the "F" slip plane will display groundwater conditions as effected by slipped debris and not clay. Thus, the boundary flowline now follows the Chama Bed and then traces the contours of the "F" slip surface, as indicated in Figure 32 as a light blue line. The boundary flowline stops where the bottom scrap of colluvium joins the top scarp of denser material. It is suggested that the groundwater seepage point for the undercliff is located at this juncture. This assumption is acceptable, as site visits to the cliffs confirms that water is seeping out of the undercliff at this level.

Now that the boundary flowline has been established, considering the effects of the Middle Barton Clay and the "F" plane, a groundwater flownet can be developed.

Two separate flownets of the same slope section have been analysed to test the sensitivity of the pore pressure with slight changes in groundwater level. The two flownet are identified as;

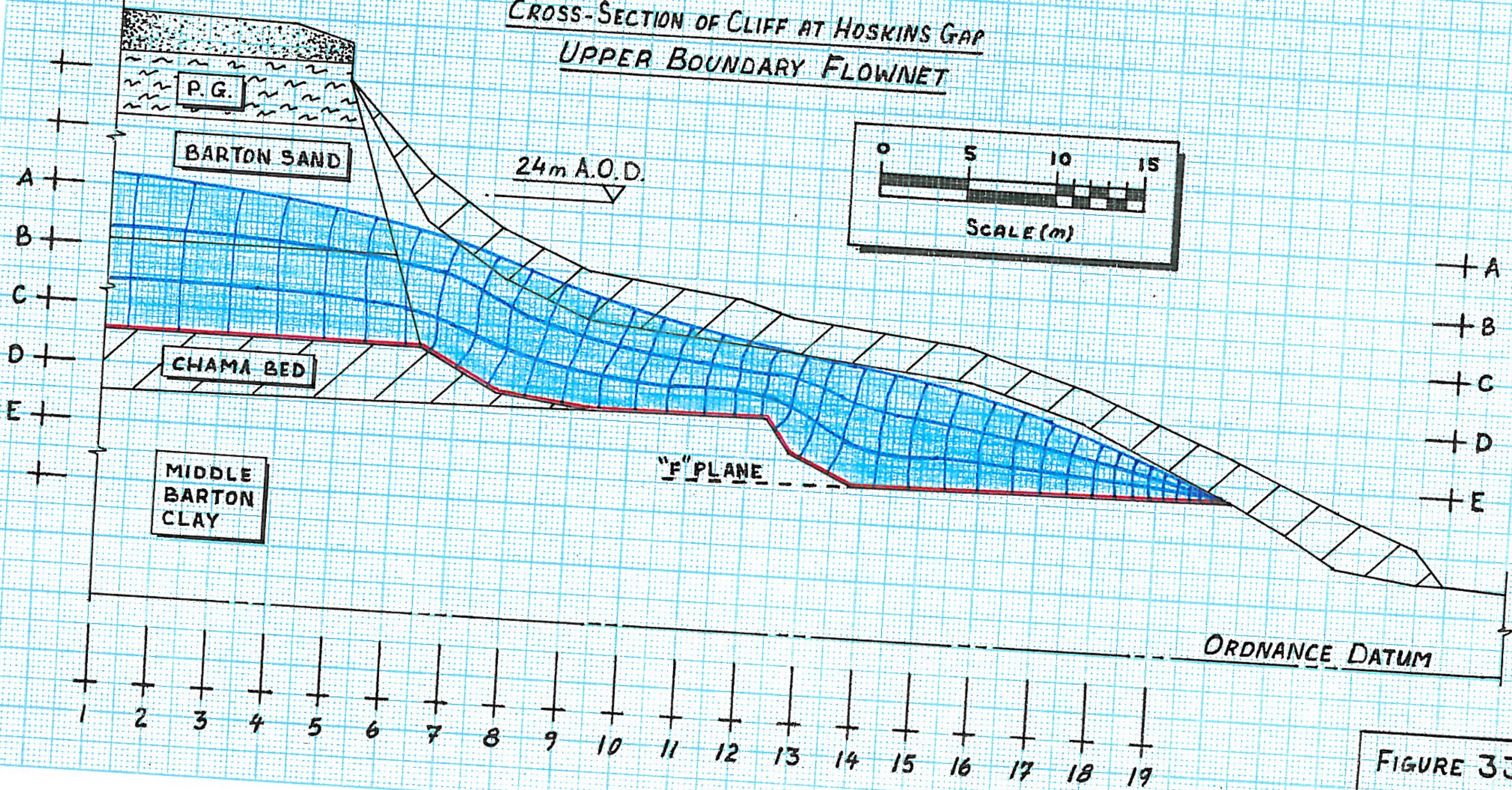
**Case 1** - Upper boundary maximum groundwater level

**Case 2** - Lower boundary maximum groundwater level

Figure 33 & Figure 34 are flownets of the slope section at Barton-on-Sea, representing, respectively, upper and lower boundary groundwater levels estimated for a likely worst period, usually experienced in the month of March. The calculations converting the groundwater pore pressures into an average pore pressure ratio are given in Appendix B. An initial groundwater level of 24.0m AOD, for the flownets, has been generated from several borehole standpipes within the Upper Barton Sand in the cliff top area. These borehole standpipe readings are for the period of early March, which experiences the rainfall and groundflow from the preceding winter months of January and February, resulting in high groundwater levels in March. When the groundwater level within the cliff top is 24.0m AOD, the undercliff slope displays an average $R_u$ ratio of;

**0.55** - Case 1 (Upper)

**0.49** - Case 2 (Lower)



CROSS-SECTION OF CLIFF AT HOSKINS GAP

UPPER BOUNDARY FLOWNET

FIGURE 33

CASE 1

## CROSS-SECTION OF CLIFF AT HOSKINS GAP

## LOWER BOUNDARY FLOWNET

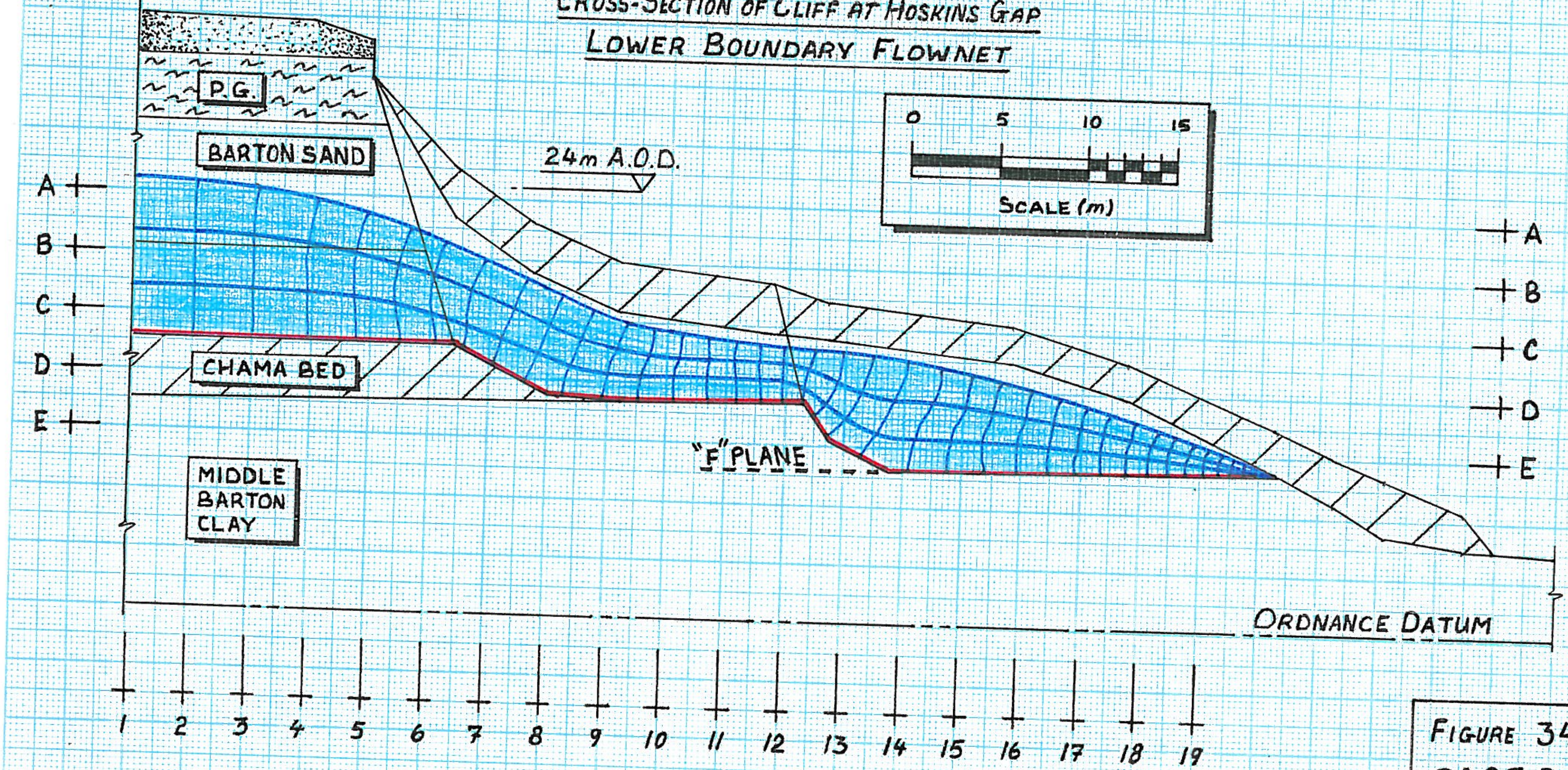


FIGURE 34
CASE 2

There is approximately a 10% difference between the two average pore pressure ratio values calculated using the flownets. This difference amounts to 0.06 in the total average pore pressure estimated to be within the slope. An average of the upper and lower maximum boundary estimates can be made, resulting in a realistic average pore pressure ratio of 0.52 for the cliff slope at Barton-on-Sea during the worst period, the month of March.

### 5.6.3 Correlation of Flownet & Slope Stability

The slope stability analysis of this report identified that the undercliff at Barton-on-Sea shall fail as an entire slope slip when an average pore pressure ratio of 0.41 is reached. As mentioned earlier an expected average pore pressure ratio for the slope would be 0.5 (authors approximation), this figure is supported by the flownet analysis where a ratio of 0.52 was established. The two values are similar, thus the author is confident that this average pore pressure ratio of 0.52 is substantiated to a reasonable degree.

Now that an average pore pressure ratio specific to the undercliff has been identified, a representative correlation can be made with the stability analysis. This correlation can be further manipulated to establish the amount of groundwater the drainage systems are retracting from the undercliff.

It is a fact that the undercliff slope at Hoskins Gap does not fail through slippage during the wet season of each year, but does fail during or immediately after adverse weather conditions. It can be assumed that during normal winter periods the cliffs saturation level is quite high but the cliff is still stabile. The stability analysis determined a maximum average pore pressure distribution ratio of less than 0.41 could occur.

Figure 35 illustrates the failure pattern for the factor of safety of the undercliff slope at Barton-on-Sea, as calculated in the stability analysis. The calculated failure point, *FOS* equals 1, corresponds to the average pore pressure ratio of 0.41, where 0.52 is the estimated potential value without the current drainage scheme. The difference in the ratio's is 0.11, as indicated on Figure 35, this difference would correspond to a large change required in the groundwater profile. On the assumption that these figures are within reasonable accuracy, it can be concluded that the drainage systems present in the undercliff, as a combined system, have to withdraw enough water to reduce the pore pressure by at least this difference. This difference increases to 0.19 in the average pore pressure ratio if a *FOS* of 1.2 is desired.

These pore pressure ratios can be converted into groundwater levels, this is discussed in the next section for further studies.

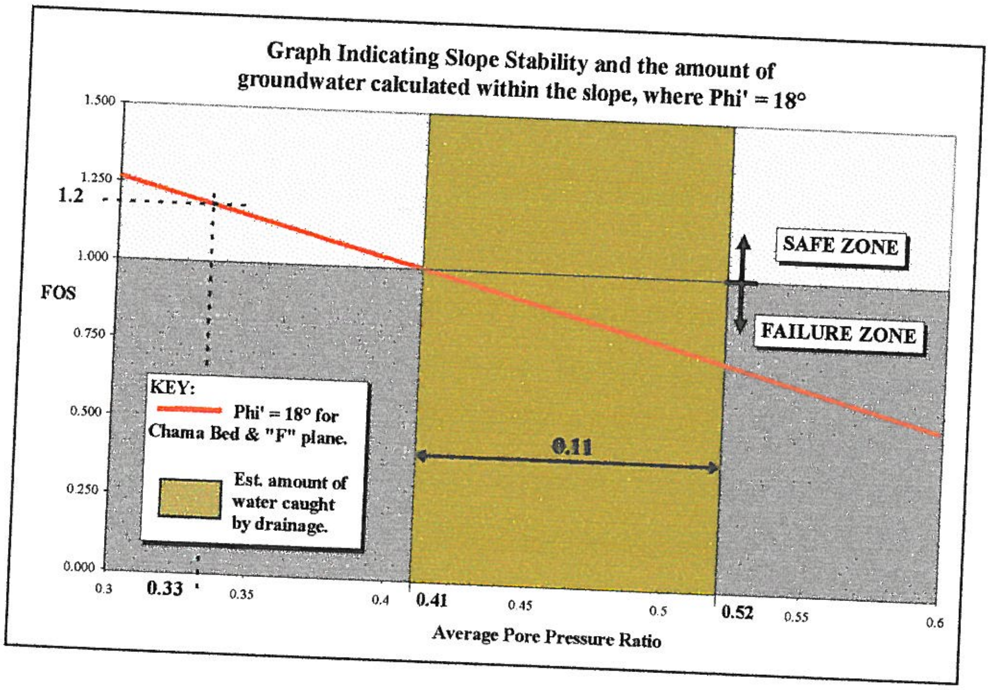


***Figure 35 - Graph of predicted stability conditions for the undercliff slope at Hoskins Gap, Barton-on-Sea.***

## 5.7 Recommendations & Further Study

The investigation into the slope stability is by no means complete, much of the data required for the analysis had been estimated, approximated or crudely calculated from information provided by various sources. These sources did not always correlate, leaving judgement up to the author. Although the author has confidence in the data generated in this report, the validity of the data obtained is unknown. It has been made clear which sections of data are suspect while unsure data has not been used in this analysis. It is recommended that a full site investigation specifically aimed at the objective of a slope stability analysis should be undertaken. The high cost implications of a site investigation are recognised, but to fully understand the cliffs stability and also to establish the effectiveness of Mole Drains, then it is imperative.

Due to the time constraints invoked on this project several exercises and studies proceeding the stability analysis were not initiated. It is recommended that these related actions are executed as these will further benefit the understanding of the cliff stability and will provide essential information for a precise analysis of the Mole Drains.

The following is a list of actions recommended for further study;

- Convert the average $R_u$ ratio values from Figure 26 & Figure 27 into ground water levels. This is a worth while exercise despite it being a cumbersome and time consuming task. It has not been done for this report due to a recent slip failure at Hoskins Gap during December 1997, thus rendering the conversion worthless. No thorough site investigation has been made so the exact profile and extent of this recent failure is unsure, but it is believed by NFDC to be an entire slope slip as identified in the analysis. This information of a slope failure was not received by the author's until early March 1998, by which time a revised analysis was intangible if the project submission date was to be met. A revised slope stability analysis is required before the conversion into groundwater levels commences, where the critical water levels are useful to the NFDC for recommending further protective remedial works.

- Establish the true phreatic surface in the undercliff slope at Barton-on-Sea throughout the year. This will identify the potential danger areas of the slope where large pore pressures are present. By establishing the groundwater conditions that occur in the slopes, superior analysis can be made, not only in the stability analysis but also in approximating the efficiency of the Mole Drains.

- Continue the analysis in terms of considering different $r_u$ values for each soil strata. For simplification of the initial analysis $r_u$ remained constant for each strata. As already noted, $r_u$ alters in strata that has been excavated or re-profiled, but the fact that $r_u$ is different for each strata type requires further analysis. This relies on the extent of advanced site investigation to that done to date.

- Deeper Investigation into the slipped material and re-analyse if required. The slip material that occupies the two top strata layers as shown in Figure 23 have been approximated from the borehole data available. Further investigation, although extremely beneficial, would not be considered cost effective in any term except for establishing accurate precipitation rates which affect the efficiency of the Mole Drains. This need for further investigation has to be examined deeper for its other advantages before it can be considered.

# 6. FUTURE WORK

## 6.1 Aim of a Future Project

The original conception for this project was to make a study of a new technology for cliff drainage, namely that of Mole Drainage systems. Initially it was thought that enough records and monitoring data of various natures were available to make this study comprehensive, unfortunately much vital information was not available. With the difficulties encountered throughout this project in pursuit of this unattainable goal, it is now possible to outline the data which would be required to assess the effectiveness of Mole Drainage technology for a future project.

The exact aim of a future research project must firstly be explained. The ultimate objective would be to come up with a method for the design of Mole Drainage systems for effective placement in a given environment. This is no easy feat and can be broken down into a series of questions needing answers with separate research requirements. It should be understood here that when placing the drains, they are only being considered with respect to permeable overlying strata (as is the case at Barton-on-Sea). The problems of going through confined layers with wildly varying piezometric heads are not currently considered to be suitable for Mole Drainage systems, however since each situation is different this is a problem specific consideration.

The questions requiring clarification are outlined below:

1. To understand how the placement of a Mole Drain affects the existing strata and what affect the removal of fines by the Moles has on the stability of the surrounding soil.
2. Can any problems (from 1) be overcome by the selection of suitable pipeline material?
3. What arrangement of pipelines would be the most effective and what would be the best profile of the pipelines?

4. How much drawdown in water level occurs after the installation of Mole Drains?
5. How much water are the drains removing and what is their response time to a given rainfall event, what are the longer term trends?

These five questions can be answered through worked experiments?

## 6.2 Research Experiments

### 6.2.1 Soil Testing

It has been clearly observed that fine soil particles are being washed through the moles into the manholes and catchpits. This must have an effect in terms of the soil properties of the surrounding strata, what exactly this is, needs to be ascertained. Several distinct possibilities exist.

1. The washing out of the fines creates preferred pathways of drainage towards the Mole Drains, aiding in the drainage process.
2. The washing out of fines weakens the shear strength of the soil and makes further slippage more likely.
3. The washing out of fines causes a combination of possibilities 1 & 2.
4. The washing out of fines is not significant and should not be a consideration.

The main concern is that possibility 2 is correct. This could be verified simply by taking soil samples around the citing of a Mole Drain before placement and some time after placement (say one year). The samples would need to be from a variety of different depths and distances from the Moles.

Quantities of sediment found within a manhole could also be monitored on a monthly basis, this would detect any changes in the rate of internal erosion of the soil.

### 6.2.2 Pipelines

The pipelines utilised were custom built for the application, they were the first of their kind and as such, no commercial pipelines were available. They consisted of a 75mm external diameter MDPE pipes with 10mm holes at 75mm close centres hand-drilled into the circumference to create the necessary perforations for water to drain through. This arrangement clearly does allow the water to drain through, but is it the best arrangement? Especially when considering the fine soil particles which are able to wash through it, is there some way to test how a pipeline might function and to use this knowledge to improve on the design?

Any pipeline must be practical in that it would need to be able to survive the Mole installation process, some kind of geotextile lining around the pipe might be ideal but how could this be installed?

In Rendel Geotechnics initial report (1994) on the Mole Drains it was suggested that two pipelines might be installed one inside the other with a filter medium between the inner lining of the outer pipe and the outer lining of the inner pipe. The outer pipe could then be withdrawn after installation leaving just the filter medium and inner pipeline, the medium could consist of stones or geotextile. The difficulty with this method would lie in the flushing through of any particulate filter material. After correspondence with Rendel other options were brought to the groups attention for the installation of a filter fabric (geotextile):

- As a sock around a single drain pipe.
- As an internal liner between an inner and outer pipe.
- As a liner between an inner and outer drain pipe, using rubber or grout "O" rings to prevent flow in the annulus between the two pipes.

The last of these options would probably be the most satisfactory, though also the most expensive. In all cases none of these methods have been tried before, and there is no guarantee over the integrity of the filter. Fine filters may also become clogged as a result of the formation of iron-hydroxide gels.

If a filter medium were practical there is still the consideration of how to perforate the pipe and what size of pipe would be most efficient. The size of the pipe which would be most efficient is likely to be a function of the amount of water which would be removed. The type of flow would ideally at all times be open channel, if the pipe were to fill completely (causing pipe flow) this would create pressure within the pipe which would act to expel the water, at some point this pressure could exceed the water pressure outside the pipe thus redistributing water back into the ground.

There is also some debate over what happens to water that enters the Mole Drain near its end; Does it flow through the mole all the way to the manhole, or is it possible that the water could be picked up in an overlying strata with a different piezometric head to lower strata and then flow back out of the pipe into the ground. The variation in piezometric head (even between two permeable strata) could be due to a lag time for flow across the boundary between the two media after a rainfall event. In the case of Barton on sea it has been suggested that this might be the case between the Plateau Gravel and Upper Barton Beds due to a build up of fines at the boundary with higher localised resistance to flow. If this were the case then it would be desirable to prevent water from leaving the Mole pipeline once it has entered. This would be difficult and perhaps impossible, it might at least in part be achieved by locating perforations on the top half of the pipeline only. This would present problems during installation and may not be worth the additional effort, depending on what, if any significance is placed on redistribution of water to lower lying strata.

A suggested experiment by Rendel (1994) was to insert a small camera into some of the Mole pipelines to detect where water was entering into the pipeline and how much silt if any had accumulated within the pipe. This work has still to be accomplished.

Additionally a relatively simple modelling experiment could be undertaken to determine the best type of pipeline effective in various medium with various filter surrounds. Very basically the experiment would consist of:

A short length of pipe (possibly 2 or 3 metres) surrounded by soil characteristic of the strata to be drained within a controlled environment (laboratory). This would facilitate comparison of the different arrangements, a fixed amount of water would be discharged into the soil and the ground water level and discharge through the pipe could be recorded as well as the volume of sediment removed.

The experiment could be refined during the course of the work, it might also be possible to model a full cliff section to look at the wider picture though benefits to this approach probably do not outweigh costs especially with the lab distorted conditions.

### 6.2.3 Survey of Installation

The Mole Drains were initially installed with the aim to have a nominal maximum spacing at the ends of the moles at the clifftop of 20m using the minimum number of manholes (Rendel). This was based on the "feeling" of the engineers at Rendel responsible. The aim of the subsequent monitoring was in part to optimise the arrangement for future design. Unfortunately the lack of any accurate knowledge of the position of the Mole Drains has acted as a major obstacle to achieving this. Information required includes grid references of the manholes, Mole Drain entrances and exits, as well as the reduced levels and the profile of the moles between each end. To obtain the grid refs. of the visible parts of the scheme is relatively simple, however the profiles of the installed Mole pipes could not easily be surveyed.

During installation this information could (and should) have been recorded, however since it was not, to understand what arrangement of pipelines would be the most effective, and what would be the best profile of the pipelines, it may be simpler to start again. That is to say since no knowledge on this issue is readily obtainable from the existing installations, from a purely research point of view, selection of an appropriate site and installation of new Mole Drains is desirable.

The installation should be into known strata carefully chosen for its simplicity and homogeneity, at all times during drilling, records should be kept of the position of the Mole head.

### 6.2.4 Groundwater Monitoring

To understand the effectiveness of the drawdown requires knowledge of the groundwater levels before and after installation of the Mole Drains. At Barton this information is lacking. Therefore continuing the theme from the previous subsection, this data could be obtained from a new site of installation provided that piezometers were installed prior to the placement of the Mole Drains. These should be monitored for at least a year prior to placement of the moles, preferably a lot longer so that it can be clearly seen what effect the moles have, without there being any doubt that any changes could be due to natural variation.

### 6.2.5 Flow Monitoring

The flow monitoring of the cliffs at Barton-on-Sea has not been entirely satisfactory from a research point of view, it has been conducted piecemeal by two different monitoring bodies, with significant gaps in the data.

Ideally data is required to ascertain how the Moles respond to a rainfall event as well as the longer term trends.

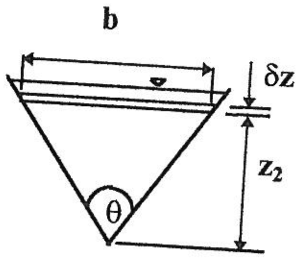
To begin with, monitoring needs to be conducted on a quarter hourly basis with corresponding rainfall monitoring, once enough data has been built up to understand how responsive the moles are then monitoring could be continued less frequently.

The monitoring will also detect long term base flows and whether or not expected effects occur with their severity. In the medium term flows are expected initially (after installation) to be high until equilibrium conditions prevail, flows may also reduce if the pipes become clogged, subsequent jetting may, or may not, be effective to prevent this. Monitoring should also show how frequently jetting is necessary.

Clearly it is impractical to monitor the flows so frequently by manual means, fortunately it should be possible to automate a monitoring procedure for at least some of the pipeflows. This would be expensive in the short term to set up but after the initial outlay, there would be some pay back in the form of reduced manual trip monitoring costs.

Automated flow monitoring systems typically consist of some kind of hydraulic control structure with an electronic depth ruler, with the known characteristics of the section and control structure this can be converted into a rate of flow. Selection on the type of control structure depends upon the range and size of flow expected.

For the flows in question the most practical hydraulic structure would be a **"Vee Weir"** this is considered accurate over the low flows present at the Barton-on-Sea Mole Drains. Mole Drains chosen for monitoring should be those with the most consistent flows since the system will break down for very low flows or flows which "swamp" the structure.



$$Q_{ideal} = \frac{8}{15}\sqrt{2g}\tan\left(\frac{\theta}{2}\right)h_1^{5/2}$$

$$b = 2z_2 \tan\left(\frac{\theta}{2}\right)$$

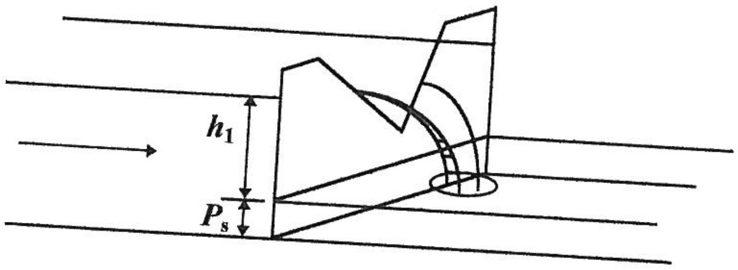


*Figure 36 - Vee-Weir Diagrams and Equations for a Rectangular Channel*

Usually $\theta$ is set at 90° therefore it is possible to work out the height $h_1$ necessary that the structure will not become overflown for the range of discharges expected to occur.

In the case of these Mole Drains, suitable flows for measuring could vary:

$$Q_{min} = 5l/\text{m} = 83.33 \text{ x } 10^{-6}\,\text{m}^3/\text{s}$$

$$Q_{max} = 15l/\text{m} = 250 \text{ x } 10^{-6}\,\text{m}^3/\text{s}$$

Rearranging the equation for flow shown as part of

Figure 36 and multiplying out the constants gives:

$$h_1 = (Q_{ideal}/0.978\text{Cd})^{2/5}$$

Cd being a coefficient due to loss of energy, for θ = 90° Cd = 0.59 the required values of height $h_1$ are:

$$h_{1min} = 29.09\text{mm}$$

$$h_{1max} = 45.14\text{mm}$$

Height $P_s$ must be sufficient that there is a gap between the base of the Vee and the downstream flow.

These values are practical for the flows and sizes of pipeline in question, they have been calculated here for a rectangular channel though in fact the pipes are circular. Rectangular channels could be fitted to the exits of the mole pipelines within the manholes. The calculation can also be modified for a circular channel, due to the added complexity it may be helpful to construct a design chart for this. Basic theory on the design of Vee Weirs can be found in a good hydraulics textbook such as those listed in the bibliography at the end of this report.

Now that a suitable control structure has been selected the upstream depth requires monitoring. This is facilitated by a sonic transducer, positioned above the flow so that it produces a sonic beam perpendicular to the water surface, this combined with a data logger and inputs on the characteristics of the control structure can be set up to convert readings directly into flows. Alternatively the depth alone can be recorded and converted to flows utilising a spreadsheet. A data logger will typically be capable of logging 45 days worth of flows every 15 minutes. The system has an accuracy of 0.25% of range.

One complete system will cost approximately £1000, economies may be made if more than one pipe flow is monitored by utilising the same data logger and power pack.

A new citing of a Mole Drain installation might also consider placement within an easily defined catchment area so that water balance calculations can be made confidently.

## 6.3 Similar Technologies

Though Mole Drains are unique several similar technologies exist, these are also relatively new and/or uncommon.

Horizontal drains (Which will not be explained fully here) have been in use since the 1930's around the world, some exist in the U.K, the technology is also relatively common in Hong Kong and several studies have been made, this has led to the development of some design procedures. If a method for the design of Mole Drainage systems is to be invented it would undoubtedly be similar to methods utilised for the design of horizontal drainage systems. The theory for horizontal drains is simpler due to the pipes being parallel to each other and (almost) horizontal. Any person continuing work on Mole Drains would be wise to familiarise themselves with horizontal drain technology, a good starting text is included at the end of this report.

Beach Management systems, a Dutch invention rely on the pump assisted drainage of beaches to prevent erosion, the typical sand conglomeration of a beach is in many ways similar to the sandy cliffs at Barton-on-Sea. There is currently research being undertaken at Southampton University into this technology and progress may have some implications towards Mole Drain technology. Some texts are again included at the end of this report.

## 6.4 Summary

The design of Mole Drains is very much three dimensional, it requires a great deal of thought power to unlock the secrets to its understanding, this is highlighted by the fact that no commercially available computer package is up to the task to date. Progress towards a greater understanding can only currently be made through a great deal of practical research. This needs to be undertaken in the field at a new site of carefully selected, known, properties. Some monitoring of the pre-installation ground conditions will be necessary with peizometers installed. The research may be supplemented with some lab-based experiments into suitable pipe and filter medium.

# 7. CONCLUSION

This report has comprised two main facets, though primarily envisaged as a study of "Mole Drains", analysis of the specific problems of the cliff instability at Barton-On Sea has taken up most of this report.

## 7.1 Soil Cliffs

In respect of the soil cliffs the water balance and slope stability analysis has been conducted, the main points of which were:

- The volume of water seepage in this area is greater than that for adjacent coastline. This explains why this area is so prone to slippage.
- The vast majority of the water present is being picked up by the drainage schemes. Though interception is not necessarily occurring soon enough to prevent slippage.
- The slope failure mode is dependent on the values of $\phi'$ of the slip plane/s. The analysis implies that failure mode 1, a front slip, applies when $\phi'$ is equal to or less than 14° and values above 14° correlate to failure mode 2, an entire slope slip.
- $\phi'$ has been variously reported to be between 12° to 18°. A $\phi'$ value equal to 18° is believed the most likely by the authors of this report for the Chama Bed and the "F" plane. This implies that the undercliff slope section at Barton-on-Sea will fail as an entire slip (mode 2) when an $R_u$ value of 0.41 is reached.
- This $R_u$ value of 0.41 corresponds to a critical *FOS* of 1.0 when a *FOS* of 1.2 or 1.5 if possible is recommended. For a *FOS* of at least 1.2 for $\phi'$ equal to 18°, the pore pressure ratio, $R_u$, has to be less than 0.32 this reduces to 0.20 for a *FOS* of 1.5.

- However without the drainage measures in place a realistic estimate of the peak yearly winter values of $R_u$ would suggest around 0.6 as a maximum value, with around 0.5 as a normal annual winter level. This suggests that the slope would fail during the wet seasons, even those which are not necessarily of adverse conditions. These values of $R_u$ are supported by the flownet analysis where a ratio of 0.52 was established.

Therefore the drainage schemes in place must at all times be sufficient to draw down water levels to maintain $R_u$ below 0.41 to prevent failure. With the instability experienced along this stretch since late 1997 it is clear that drainage measures in place are not sufficient for extreme conditions. The water balance calculation identified that water draining from this stretch of cliff could have fallen as rain as long as three months ago. It would be realistic therefore for this area to be put on alert for landslip after three months of consecutive torrential rainfall have accrued. Torrential rainfall could be considered to have occurred if monthly totals approach or exceed 100mm per month or the three month total approaches or exceeds 300mm. Though it would be wise to exercise judgement over this definition since groundwater recharge, amount of surface flow and type of rainfall event, will all affect the amount of water entering the ground.

## 7.2 Mole Drains

In respect of the Mole Drains at Barton-on-Sea several facts should be emphasised:

- The second set of Mole Drains installed in May 1994 cost £10,000. This set contained five drains with a total pipe length of 170m where one pipe extended 60m through the cliff.

- This equates to £58 per linear metre of pipeline for a "typical" system as they are currently envisaged.

- It took just 5 days to install the first four Mole Drains with a total length of 115m.

- Note that the previous two points represent significantly quicker and cheaper construction and installation than any conventional remedial measures.

- The Mole Drains have consistently extracted water since their installation.

Scrutiny of the monitoring data also revealed that the Mole drains cover 37% of the stretch and about 20% of water extraction. This is to be expected in that the Mole Drains were intended only to complement the conventional stabilising measures, the idea being to draw water levels down before they could contribute to increased pore water pressures within the undercliff. Specifically it has been identified that the Chama Bed and the “F” plane, are responsible for the slip failures experienced.

Unfortunately the ultimate aim “to produce a method for the design and placing of these drains” has proven beyond this project, not least due to the complexity of the three dimensional problem, but also because there is a dearth of valuable information on the subject. The research and practical work required to ascertain the necessary data was outlined in Chapter 6. It is hoped that the production of this report will act as a stepping stone to achieving this ultimate objective.

# 8. GLOSSARY

| | |
|---|---|
| $\phi$ | Angle of Soil Friction. |
| $\phi'$ | Effective Angle of Soil Friction. |
| AE | Actual Evapotranspiration. |
| AOD | Above Ordnance Datum.<br>(Mean Sea Level at Newlyn, Cornwall, England) |
| $c$ | Soil Cohesion. |
| $c'$ | Drained Cohesion of Cohesive Soil. |
| CP | Catch-Pit |
| FAO | Food and Agricultural Organisation of the United Nations. |
| $FOS$ | Factor of Safety. |
| MH | Man-Hole. |
| NFDC | New Forest District Council. |
| OS | Ordnance Datum. |
| PE or $ET_o$ | Potential Evapotranspiration. |
| pwp | Pore Water Pressure. |
| $R_u$ | Average Pore Pressure Ratio. |
| $r_u$ | Pore Pressure Ratio. |
| S.U. | Southampton University. |
| $u$ or $U$ | Water Pressure |

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# APPENDIX A

Penman Montieth Calculations

Effective Rainfall Calculations

# PENMAN-MONTEITH CALCULATIONS 1990

Key
All information in Blue has been entered by hand
Information in red is the output used for the next part of the water balance calculation

Give : Station name : BARTON ON SEA
Latitude : 51.00 51.00 0.89 rad
Altitude : 30 m.

Parameters : Short Wave Rad a = 0.25 b = 0.50 alpha=
Albedo alpha = 0.23
Long Wave Rad. a = 0.90 b = 0.10
al = 0.34 bl = -0.139

Instrument height wind temp Cropheight AeroT Cff
AerDyn Resistance ra * U = 206 200 190 12 900
Grass Alfalfa
Canopy resistance rc = 70 86 12

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tmax | 10.4 | 11.2 | 11.8 | 13.6 | 18.4 | 17.0 | 21.9 | 22.7 | 19.1 | 16.1 | 10.8 | 7.9 |
| Tmin | 5.4 | 6.3 | 5.6 | 4.3 | 8.6 | 10.8 | 12.6 | 13.5 | 9.7 | 10.3 | 5.8 | 3.3 |
| RHmean | 93 | 91 | 87 | 82 | 84 | 88 | 84 | 86 | 84 | 90 | 93 | 90 |
| RHmin | 77 | 76 | 69 | 57 | 58 | 70 | 60 | 62 | 59 | 73 | 77 | 76 |
| Wind (km/d) | 272 | 333 | 205 | 217 | 175 | 198 | 218 | 188 | 175 | 243 | 196 | 210 |
| Sunhours | 1.52 | 3.24 | 5.15 | 8.13 | 9.63 | 4.60 | 10.18 | 8.64 | 6.34 | 3.52 | 3.02 | 1.95 |
| ET fao mm/day | 0.36 | 0.72 | 1.29 | 2.27 | 3.11 | 2.53 | 3.71 | 3.14 | 2.14 | 1.03 | 0.47 | 0.36 |
| Avg Temp | 7.90 | 8.75 | 8.70 | 8.95 | 13.50 | 13.90 | 17.25 | 18.10 | 14.40 | 13.20 | 8.30 | 5.60 |
| n/N | 19% | 33% | 44% | 59% | 63% | 28% | 64% | 61% | 51% | 34% | 35% | 25% |
| Wind (m/s) | 3.15 | 3.85 | 2.37 | 2.51 | 2.03 | 2.29 | 2.52 | 2.18 | 2.03 | 2.81 | 2.27 | 2.43 |
| Ea(Tmax) | 1.26 | 1.33 | 1.38 | 1.56 | 2.12 | 1.94 | 2.63 | 2.76 | 2.21 | 1.83 | 1.30 | 1.07 |
| Ea(Tmin) | 0.90 | 0.95 | 0.91 | 0.83 | 1.12 | 1.30 | 1.46 | 1.55 | 1.20 | 1.25 | 0.92 | 0.77 |
| Ea(Tx)-Ea(Tn) | 1.08 | 1.14 | 1.15 | 1.19 | 1.62 | 1.62 | 2.04 | 2.15 | 1.71 | 1.54 | 1.11 | 0.92 |
| Edew | 0.98 | 1.01 | 0.95 | 0.89 | 1.22 | 1.36 | 1.57 | 1.70 | 1.31 | 1.34 | 1.00 | 0.81 |
| RH(max-min) | 93% | 91% | 87% | 82% | 84% | 88% | 84% | 86% | 84% | 90% | 93% | 90% |
| Dlt(ETx-ETn) | 0.07 | 0.08 | 0.08 | 0.08 | 0.10 | 0.10 | 0.13 | 0.13 | 0.11 | 0.10 | 0.08 | 0.06 |
| P-atm. | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 |
| lambda | 2.48 | 2.48 | 2.48 | 2.48 | 2.47 | 2.47 | 2.46 | 2.46 | 2.47 | 2.47 | 2.48 | 2.49 |
| gamma | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 |
| rc | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 |
| ra | 65 | 53 | 87 | 82 | 102 | 90 | 82 | 95 | 102 | 73 | 91 | 85 |
| gamma* | 0.14 | 0.15 | 0.12 | 0.12 | 0.11 | 0.12 | 0.12 | 0.12 | 0.11 | 0.13 | 0.12 | 0.12 |
| dl/dl+gm* | 0.35 | 0.34 | 0.39 | 0.39 | 0.48 | 0.47 | 0.51 | 0.54 | 0.49 | 0.44 | 0.39 | 0.35 |
| gm/dl+gm* | 0.32 | 0.29 | 0.34 | 0.33 | 0.31 | 0.30 | 0.27 | 0.27 | 0.30 | 0.29 | 0.35 | 0.36 |
| Aeroterm | 0.33 | 0.47 | 0.50 | 0.81 | 0.77 | 0.55 | 0.98 | 0.82 | 0.76 | 0.51 | 0.28 | 0.32 |
| Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| dayno | 15 | 46 | 76 | 107 | 137 | 168 | 198 | 229 | 259 | 290 | 320 | 351 |
| soldeclin | -0.370 | -0.230 | -0.033 | 0.179 | 0.334 | 0.408 | 0.372 | 0.233 | 0.036 | -0.176 | -0.336 | -0.408 |
| xx | -0.281 | -0.178 | -0.026 | 0.138 | 0.255 | 0.308 | 0.282 | 0.179 | 0.028 | -0.136 | -0.256 | -0.308 |
| yy | 0.587 | 0.613 | 0.629 | 0.619 | 0.595 | 0.578 | 0.586 | 0.612 | 0.629 | 0.620 | 0.594 | 0.578 |
| omega | 1.07 | 1.28 | 1.53 | 1.80 | 2.01 | 2.13 | 2.07 | 1.87 | 1.62 | 1.35 | 1.13 | 1.01 |
| dr | 1.03 | 1.02 | 1.01 | 0.99 | 0.98 | 0.97 | 0.97 | 0.98 | 0.99 | 1.01 | 1.02 | 1.03 |
| Ra | 8.28 | 13.83 | 22.32 | 31.73 | 38.54 | 41.71 | 39.99 | 33.79 | 25.10 | 15.95 | 9.54 | 6.89 |
| N | 8.18 | 9.75 | 11.68 | 13.72 | 15.38 | 16.30 | 15.84 | 14.27 | 12.34 | 10.30 | 8.60 | 7.70 |
| Rns | 2.2 | 4.4 | 8.1 | 13.3 | 16.7 | 12.6 | 17.6 | 14.4 | 9.8 | 5.2 | 3.1 | 2.0 |
| f(n/N) | 0.27 | 0.40 | 0.50 | 0.63 | 0.66 | 0.35 | 0.68 | 0.64 | 0.56 | 0.41 | 0.42 | 0.33 |
| sigma(Tx_Tn) | 30.59 | 30.96 | 30.95 | 31.09 | 33.15 | 33.30 | 34.91 | 35.32 | 33.56 | 32.97 | 30.77 | 29.60 |
| emissivity | 0.20 | 0.20 | 0.20 | 0.21 | 0.19 | 0.18 | 0.17 | 0.16 | 0.18 | 0.18 | 0.20 | 0.22 |
| Rbo | 6.19 | 6.19 | 6.32 | 6.49 | 6.16 | 5.91 | 5.77 | 5.60 | 6.06 | 5.89 | 6.17 | 6.35 |
| LWR | 1.66 | 2.47 | 3.14 | 4.12 | 4.10 | 2.10 | 3.93 | 3.62 | 3.42 | 2.40 | 2.57 | 2.09 |
| Rn (Rns-Rl) | 0.53 | 1.96 | 4.94 | 9.23 | 12.61 | 10.46 | 13.67 | 10.77 | 6.38 | 2.76 | 0.55 | -0.09 |
| G | 0.32 | 0.12 | -0.01 | 0.04 | 0.64 | 0.06 | 0.47 | 0.12 | -0.52 | -0.17 | -0.69 | -0.38 |
| Rn-G | 0.21 | 1.84 | 4.95 | 9.20 | 11.97 | 10.41 | 13.20 | 10.65 | 6.90 | 2.93 | 1.24 | 0.29 |
| Rad Term | 0.07 | 0.27 | 0.78 | 1.47 | 2.46 | 1.99 | 2.83 | 2.35 | 1.28 | 0.49 | 0.09 | -0.01 |
| Rad Term(-G) | 0.03 | 0.25 | 0.78 | 1.46 | 2.34 | 1.98 | 2.73 | 2.32 | 1.38 | 0.52 | 0.20 | 0.04 |
| ETcomb | 0.40 | 0.74 | 1.29 | 2.28 | 3.23 | 2.54 | 3.81 | 3.17 | 2.04 | 1.00 | 0.36 | 0.30 |
| | 11.3% | 2.2% | -0.1% | 0.2% | 3.8% | 0.4% | 2.5% | 0.8% | -5.1% | -3.0% | -29.8% | -17.3% |
| ET (-G) | 0.36 | 0.72 | 1.29 | 2.27 | 3.11 | 2.53 | 3.71 | 3.14 | 2.14 | 1.03 | 0.47 | 0.36 |

| | | | |
|---|---|---|---|
| Grass | | Alfalfa | 2.58 |
| Gamma* | Cff | Gamma*Cff | 2.8% (STD) |
| 0.34 | | 0.42 | 2.56 |

PENMAN-MONTEITH CALCULATIONS 1991

Key
All information in Blue has been entered by hand
Information in red is the output used for the next part of the water balance calculation

Give : Station name : BARTON ON SEA
Latitude : 51.00 51.00 0.89 rad
Altitude : 30 m.

Parameters : Short Wave Rad a = 0.25 b = 0.50 alpha=
Albedo alpha = 0.23
Long Wave Rad a = 0.90 b = 0.10
al = 0.34 bl = -0.139

Instrument height wind 200 temp 190 Cropheight 12
AerDyn Resistance ra * U = 206 AeroT Cff 900
Grass 70 Alfalfa 86
Canopy resistance rc = 12

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tmax | 7.3 | 5.1 | 11.0 | 12.2 | 15.5 | 15.5 | 20.5 | 21.0 | 20.0 | 14.0 | 10.9 | 8.5 |
| Tmin | 3.1 | -0.5 | 5.4 | 4.8 | 7.0 | 9.4 | 12.9 | 12.8 | 11.4 | 8.1 | 4.8 | 4.0 |
| RHmean | 91 | 95 | 91 | 86 | 84 | 88 | 92 | 91 | 92 | 92 | 92 | 91 |
| RHmin | 77 | 76 | 74 | 65 | 61 | 71 | 70 | 68 | 67 | 74 | 73 | 77 |
| Wind (km/d) | 232 | 173 | 213 | 249 | 165 | 242 | 202 | 185 | 186 | 172 | 222 | 190 |
| Sunhours | 2.20 | 2.76 | 3.55 | 5.80 | 5.81 | 5.21 | 7.20 | 8.60 | 6.16 | 3.00 | 2.20 | 1.70 |
| ET fao mm/day | 0.36 | 0.47 | 0.93 | 1.86 | 2.42 | 2.42 | 2.85 | 2.83 | 1.90 | 0.92 | 0.53 | 0.32 |
| Avg Temp | 5.20 | 2.30 | 8.20 | 8.50 | 11.25 | 12.45 | 16.70 | 16.90 | 15.71 | 11.05 | 7.85 | 6.25 |
| n/N | 27% | 28% | 30% | 42% | 38% | 32% | 45% | 60% | 50% | 29% | 26% | 22% |
| Wind (m/s) | 2.69 | 2.00 | 2.47 | 2.88 | 1.91 | 2.80 | 2.34 | 2.14 | 2.15 | 1.99 | 2.57 | 2.20 |
| Ea(Tmax) | 1.02 | 0.88 | 1.31 | 1.42 | 1.76 | 1.76 | 2.41 | 2.49 | 2.34 | 1.60 | 1.30 | 1.11 |
| Ea(Tmin) | 0.76 | 0.59 | 0.90 | 0.86 | 1.00 | 1.18 | 1.49 | 1.48 | 1.35 | 1.08 | 0.86 | 0.81 |
| Ea(Tx)-Ea(Tn) | 0.89 | 0.73 | 1.10 | 1.14 | 1.38 | 1.47 | 1.95 | 1.98 | 1.84 | 1.34 | 1.08 | 0.96 |
| Edew | 0.79 | 0.67 | 0.97 | 0.92 | 1.08 | 1.25 | 1.69 | 1.68 | 1.57 | 1.19 | 0.95 | 0.85 |
| RH(max-min) | 91% | 95% | 91% | 86% | 84% | 88% | 92% | 91% | 92% | 92% | 92% | 91% |
| Dlt(ETx-ETn) | 0.06 | 0.05 | 0.07 | 0.08 | 0.09 | 0.10 | 0.12 | 0.12 | 0.12 | 0.09 | 0.07 | 0.07 |
| P-atm. | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 |
| lambda | 2.49 | 2.50 | 2.48 | 2.48 | 2.47 | 2.47 | 2.46 | 2.46 | 2.46 | 2.47 | 2.48 | 2.49 |
| gamma | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 |
| rc | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 |
| ra | 77 | 103 | 84 | 72 | 108 | 74 | 88 | 96 | 96 | 104 | 80 | 94 |
| gamma* | 0.13 | 0.11 | 0.12 | 0.13 | 0.11 | 0.13 | 0.12 | 0.12 | 0.12 | 0.11 | 0.12 | 0.12 |
| dl/dl+gm* | 0.33 | 0.32 | 0.38 | 0.37 | 0.45 | 0.43 | 0.51 | 0.52 | 0.50 | 0.44 | 0.37 | 0.37 |
| gm/dl+gm* | 0.35 | 0.41 | 0.34 | 0.32 | 0.33 | 0.29 | 0.28 | 0.28 | 0.29 | 0.33 | 0.34 | 0.36 |
| Aeroterm | 0.31 | 0.18 | 0.35 | 0.64 | 0.61 | 0.58 | 0.52 | 0.56 | 0.53 | 0.32 | 0.36 | 0.28 |
| Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| dayno | 15 | 46 | 76 | 107 | 137 | 168 | 198 | 229 | 259 | 290 | 320 | 351 |
| soldeclin | -0.370 | -0.230 | -0.033 | 0.179 | 0.334 | 0.408 | 0.372 | 0.233 | 0.036 | -0.176 | -0.336 | -0.408 |
| xx | -0.281 | -0.178 | -0.026 | 0.138 | 0.255 | 0.308 | 0.282 | 0.179 | 0.028 | -0.136 | -0.256 | -0.308 |
| yy | 0.587 | 0.613 | 0.629 | 0.619 | 0.595 | 0.578 | 0.586 | 0.612 | 0.629 | 0.620 | 0.594 | 0.578 |
| omega | 1.07 | 1.28 | 1.53 | 1.80 | 2.01 | 2.13 | 2.07 | 1.87 | 1.62 | 1.35 | 1.13 | 1.01 |
| dr | 1.03 | 1.02 | 1.01 | 0.99 | 0.98 | 0.97 | 0.97 | 0.98 | 0.99 | 1.01 | 1.02 | 1.03 |
| Ra | 8.28 | 13.83 | 22.32 | 31.73 | 38.54 | 41.71 | 39.99 | 33.79 | 25.10 | 15.95 | 9.54 | 6.89 |
| N | 8.18 | 9.75 | 11.68 | 13.72 | 15.38 | 16.30 | 15.84 | 14.27 | 12.34 | 10.30 | 8.60 | 7.70 |
| Rns | 2.5 | 4.2 | 6.9 | 11.3 | 13.0 | 13.2 | 14.7 | 14.3 | 9.7 | 4.9 | 2.8 | 1.9 |
| f(n/N) | 0.34 | 0.35 | 0.37 | 0.48 | 0.44 | 0.39 | 0.51 | 0.64 | 0.55 | 0.36 | 0.33 | 0.30 |
| sigma(Tx_Tn) | 29.43 | 28.23 | 30.73 | 30.87 | 32.10 | 32.63 | 34.63 | 34.73 | 34.16 | 31.99 | 30.58 | 29.88 |
| emissivity | 0.22 | 0.23 | 0.20 | 0.21 | 0.20 | 0.18 | 0.16 | 0.16 | 0.17 | 0.19 | 0.20 | 0.21 |
| Rbo | 6.35 | 6.38 | 6.22 | 6.36 | 6.27 | 6.01 | 5.50 | 5.54 | 5.66 | 6.02 | 6.23 | 6.31 |
| LWR | 2.18 | 2.27 | 2.33 | 3.06 | 2.76 | 2.34 | 2.81 | 3.57 | 3.11 | 2.18 | 2.06 | 1.89 |
| Rn (Rns-Rl) | 0.27 | 1.90 | 4.58 | 8.21 | 10.26 | 10.82 | 11.89 | 10.78 | 6.54 | 2.67 | 0.71 | 0.02 |
| G | -0.15 | -0.41 | 0.83 | 0.04 | 0.39 | 0.17 | 0.60 | 0.03 | -0.17 | -0.65 | -0.45 | -0.22 |
| Rn-G | 0.42 | 2.31 | 3.75 | 8.17 | 9.87 | 10.66 | 11.29 | 10.75 | 6.71 | 3.33 | 1.16 | 0.25 |
| Rad Term | 0.04 | 0.24 | 0.70 | 1.23 | 1.88 | 1.87 | 2.45 | 2.28 | 1.34 | 0.48 | 0.11 | 0.00 |
| Rad Term(-G) | 0.06 | 0.30 | 0.58 | 1.22 | 1.81 | 1.84 | 2.33 | 2.27 | 1.37 | 0.60 | 0.17 | 0.04 |
| ETcomb | 0.34 | 0.42 | 1.06 | 1.87 | 2.49 | 2.45 | 2.97 | 2.84 | 1.87 | 0.80 | 0.46 | 0.28 |
| | -5.7% | -12.4% | 12.0% | 0.3% | 2.8% | 1.2% | 4.1% | 0.2% | -1.8% | -14.6% | -14.5% | -11.6% |
| ET (-G) | 0.36 | 0.47 | 0.93 | 1.86 | 2.42 | 2.42 | 2.85 | 2.83 | 1.90 | 0.92 | 0.53 | 0.32 |

| | | |
|---|---|---|
| Grass<br>Gamma* Cff<br>0.34 | Alfalfa<br>Gamma*Cff<br>0.42 | 2.18<br>5.8% (STD)<br>2.17 |

## PENMAN-MONTEITH CALCULATIONS 1992

Key
All information in Blue has been entered by hand
Information in red is the output used for the next part of the water balance calculation

```
Give :         Station name :                  BARTON ON SEA
               Latitude   :                      51.00     51.00      0.89  rad
               Altitude   :                         30  m.

Parameters :              Short Wave Rad                   a  =       0.25   b  =      0.50   alpha=
                          Albedo                        alpha =       0.23
                          Long Wave Rad.                   a  =       0.90   b  =      0.10
                                                          al  =       0.34   bl  =    -0.139

                          Instrument height                           wind      temp Cropheight           AeroT Cff
                          AerDyn Resistance  ra * U =       206        200       190        12               900
                                                           Grass    Alfalfa
                          Canopy resistance    rc =          70         86                  12
```

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tmax | 7.2 | 9.0 | 10.9 | 12.7 | 18.7 | 20.6 | 20.1 | 19.5 | 17.6 | 12.9 | 12.3 | 8.2 |
| Tmin | 1.7 | 3.1 | 5.3 | 5.6 | 9.2 | 10.8 | 13.5 | 13.4 | 12.0 | 5.4 | 6.2 | 2.7 |
| RHmean | 94 | 86 | 89 | 87 | 86 | 85 | 90 | 92 | 90 | 90 | 93 | 93 |
| RHmin | 76 | 69 | 73 | 67 | 60 | 59 | 72 | 74 | 74 | 67 | 74 | 75 |
| Wind (km/d) | 174 | 163 | 245 | 228 | 186 | 153 | 201 | 253 | 197 | 192 | 232 | 176 |
| Sunhours | 2.40 | 2.80 | 2.09 | 5.45 | 9.25 | 8.25 | 5.43 | 5.20 | 4.70 | 4.20 | 2.00 | 1.70 |
| ET fao mm/day | 0.25 | 0.64 | 1.02 | 1.81 | 3.04 | 3.38 | 2.71 | 2.25 | 1.66 | 1.02 | 0.47 | 0.32 |
| Avg Temp | 4.45 | 6.04 | 8.10 | 9.15 | 13.95 | 15.70 | 16.80 | 16.45 | 14.80 | 9.15 | 9.25 | 5.45 |
| n/N | 29% | 29% | 18% | 40% | 60% | 51% | 34% | 36% | 38% | 41% | 23% | 22% |
| Wind (m/s) | 2.01 | 1.89 | 2.84 | 2.64 | 2.15 | 1.77 | 2.33 | 2.93 | 2.28 | 2.22 | 2.69 | 2.04 |
| Ea(Tmax) | 1.02 | 1.14 | 1.30 | 1.47 | 2.16 | 2.43 | 2.35 | 2.27 | 2.01 | 1.49 | 1.43 | 1.09 |
| Ea(Tmin) | 0.69 | 0.76 | 0.89 | 0.91 | 1.16 | 1.30 | 1.55 | 1.54 | 1.40 | 0.90 | 0.95 | 0.74 |
| Ea(Tx)-Ea(Tn) | 0.85 | 0.95 | 1.10 | 1.19 | 1.66 | 1.86 | 1.95 | 1.90 | 1.71 | 1.19 | 1.19 | 0.91 |
| Edew | 0.77 | 0.78 | 0.95 | 0.98 | 1.29 | 1.44 | 1.69 | 1.68 | 1.49 | 1.00 | 1.06 | 0.82 |
| *RH(max-min)* | *94%* | *86%* | *89%* | *87%* | *86%* | *85%* | *90%* | *92%* | *90%* | *90%* | *93%* | *93%* |
| DIt(ETx-ETn) | 0.06 | 0.07 | 0.07 | 0.08 | 0.11 | 0.12 | 0.12 | 0.12 | 0.11 | 0.08 | 0.08 | 0.06 |
| P-atm. | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 |
| lambda | 2.49 | 2.49 | 2.48 | 2.48 | 2.47 | 2.46 | 2.46 | 2.46 | 2.47 | 2.48 | 2.48 | 2.49 |
| *gamma* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* |
| rc | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 |
| ra | 102 | 109 | 73 | 78 | 96 | 116 | 89 | 70 | 90 | 93 | 77 | 101 |
| gamma* | 0.11 | 0.11 | 0.13 | 0.13 | 0.11 | 0.11 | 0.12 | 0.13 | 0.12 | 0.12 | 0.13 | 0.11 |
| dl/dl+gm* | 0.35 | 0.38 | 0.36 | 0.39 | 0.48 | 0.53 | 0.51 | 0.48 | 0.48 | 0.41 | 0.39 | 0.36 |
| gm/dl+gm* | 0.39 | 0.38 | 0.32 | 0.32 | 0.30 | 0.30 | 0.28 | 0.26 | 0.29 | 0.34 | 0.32 | 0.38 |
| Aeroterm | 0.20 | 0.39 | 0.45 | 0.57 | 0.75 | 0.69 | 0.53 | 0.52 | 0.45 | 0.46 | 0.35 | 0.24 |
| Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| dayno | 15 | 46 | 76 | 107 | 137 | 168 | 198 | 229 | 259 | 290 | 320 | 351 |
| soldeclin | -0.370 | -0.230 | -0.033 | 0.179 | 0.334 | 0.408 | 0.372 | 0.233 | 0.036 | -0.176 | -0.336 | -0.408 |
| xx | -0.281 | -0.178 | -0.026 | 0.138 | 0.255 | 0.308 | 0.282 | 0.179 | 0.028 | -0.136 | -0.256 | -0.308 |
| yy | 0.587 | 0.613 | 0.629 | 0.619 | 0.595 | 0.578 | 0.586 | 0.612 | 0.629 | 0.620 | 0.594 | 0.578 |
| omega | 1.07 | 1.28 | 1.53 | 1.80 | 2.01 | 2.13 | 2.07 | 1.87 | 1.62 | 1.35 | 1.13 | 1.01 |
| dr | *1.03* | *1.02* | *1.01* | *0.99* | *0.98* | *0.97* | *0.97* | *0.98* | *0.99* | *1.01* | *1.02* | 1.03 |
| Ra | 8.28 | 13.83 | 22.32 | 31.73 | 38.54 | 41.71 | 39.99 | 33.79 | 25.10 | 15.95 | 9.54 | 6.89 |
| N | 8.18 | 9.75 | 11.68 | 13.72 | 15.38 | 16.30 | 15.84 | 14.27 | 12.34 | 10.30 | 8.60 | 7.70 |
| Rns | 2.5 | 4.2 | 5.8 | 11.0 | 16.3 | 16.2 | 13.0 | 11.2 | 8.5 | 5.6 | 2.7 | 1.9 |
| f(n/N) | 0.36 | 0.36 | 0.26 | 0.46 | 0.64 | 0.56 | 0.41 | 0.43 | 0.44 | 0.47 | 0.31 | 0.30 |
| sigma(Tx_Tn) | 29.12 | 29.79 | 30.68 | 31.15 | 33.35 | 34.17 | 34.66 | 34.49 | 33.71 | 31.16 | 31.19 | 29.54 |
| emissivity | 0.22 | 0.22 | 0.20 | 0.20 | 0.18 | 0.17 | 0.16 | 0.16 | 0.17 | 0.20 | 0.20 | 0.21 |
| Rbo | 6.33 | 6.45 | 6.27 | 6.29 | 6.06 | 5.91 | 5.52 | 5.49 | 5.72 | 6.24 | 6.12 | 6.31 |
| *LWR* | *2.31* | *2.32* | 1.64 | *2.89* | *3.89* | 3.29 | *2.26* | *2.36* | 2.54 | 2.92 | 1.90 | 1.89 |
| Rn (Rns-Rl) | 0.22 | 1.88 | 4.19 | 8.08 | 12.45 | 12.87 | 10.72 | 8.89 | 5.97 | 2.65 | 0.79 | 0.02 |
| G | -0.14 | 0.22 | 0.29 | 0.15 | 0.67 | 0.25 | 0.15 | -0.05 | -0.23 | -0.79 | 0.01 | -0.53 |
| *Rn-G* | *0.36* | *1.65* | *3.90* | *7.93* | *11.78* | 12.62 | *10.56* | *8.94* | *6.20* | 3.44 | *0.78* | *0.55* |
| Rad Term | 0.03 | 0.29 | 0.62 | 1.27 | 2.43 | 2.74 | 2.21 | 1.72 | 1.17 | 0.44 | 0.12 | 0.00 |
| Rad Term(-G) | 0.05 | 0.25 | 0.57 | 1.24 | 2.30 | 2.69 | 2.18 | 1.73 | 1.21 | 0.57 | 0.12 | 0.08 |
| *ETcomb* | *0.23* | *0.68* | *1.06* | *1.84* | *3.17* | *3.44* | 2.74 | 2.24 | 1.62 | 0.89 | 0.47 | 0.24 |
| | -8.4% | 5.0% | 4.0% | 1.3% | 4.1% | 1.5% | 1.2% | -0.4% | -2.8% | -14.6% | 0.5% | -32.3% |
| ET (-G) | 0.25 | 0.64 | 1.02 | 1.81 | 3.04 | 3.38 | 2.71 | 2.25 | 1.66 | 1.02 | 0.47 | 0.32 |

```
Grass                Alfalfa                  2.28
Gamma*    Cff        Gamma*Cff                 5.7% (STD)
   0.34                 0.42                  2.27
```

PENMAN-MONTEITH CALCULATIONS 1993

Key
All information in Blue has been entered by hand
Information in red is the output used for the next part of the water balance calculation

```
Give :        Station name :               BARTON ON SEA
              Latitude     :                   51.00     51.00      0.89  rad
              Altitude     :                      30  m.

Parameters :          Short Wave Rad                       a  =      0.25     b  =      0.50   alpha=
                      Albedo                           alpha =      0.23
                      Long Wave Rad.                       a  =      0.90     b  =      0.10
                                                          al  =      0.34    bl  =    -0.139

                      Instrument height                             wind      temp Cropheight         AeroT Cff
                      AerDyn Resistance    ra * U =       206       200       190        12              900
                                                        Grass    Alfalfa
                      Canopy resistance    rc =            70        86                  12
```

|  | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tmax | 9.8 | 7.8 | 10.4 | 13.2 | 16.5 | 19.5 | 19.1 | 19.6 | 17.1 | 13.0 | 9.4 | 9.7 |
| Tmin | 5.1 | 3.3 | 3.8 | 6.5 | 8.8 | 11.4 | 12.4 | 11.3 | 10.0 | 7.0 | 2.8 | 4.1 |
| RHmean | 94 | 91 | 87 | 92 | 88 | 89 | 89 | 88 | 89 | 89 | 89 | 92 |
| RHmin | 79 | 76 | 68 | 72 | 66 | 66 | 70 | 65 | 69 | 71 | 69 | 75 |
| Wind (km/d) | 267 | 146 | 171 | 206 | 231 | 168 | 216 | 172 | 171 | 193 | 160 | 273 |
| Sunhours | 1.10 | 2.30 | 4.60 | 4.50 | 6.70 | 8.30 | 6.00 | 8.20 | 4.50 | 4.30 | 2.80 | 1.90 |
| ET fao mm/day | 0.36 | 0.57 | 1.12 | 1.60 | 2.50 | 3.16 | 2.76 | 2.76 | 1.65 | 0.97 | 0.51 | 0.35 |
| Avg Temp | 7.45 | 5.55 | 7.10 | 9.85 | 12.65 | 15.45 | 15.75 | 15.45 | 13.55 | 10.00 | 6.10 | 6.90 |
| n/N | 13% | 24% | 39% | 33% | 44% | 51% | 38% | 57% | 36% | 42% | 33% | 25% |
| Wind (m/s) | 3.09 | 1.69 | 1.98 | 2.38 | 2.67 | 1.94 | 2.50 | 1.99 | 1.98 | 2.23 | 1.85 | 3.16 |
| Ea(Tmax) | 1.21 | 1.06 | 1.26 | 1.52 | 1.88 | 2.27 | 2.21 | 2.28 | 1.95 | 1.50 | 1.18 | 1.20 |
| Ea(Tmin) | 0.88 | 0.77 | 0.80 | 0.97 | 1.13 | 1.35 | 1.44 | 1.34 | 1.23 | 1.00 | 0.75 | 0.82 |
| Ea(Tx)-Ea(Tn) | 1.05 | 0.92 | 1.03 | 1.24 | 1.50 | 1.81 | 1.83 | 1.81 | 1.59 | 1.25 | 0.96 | 1.01 |
| Edew | 0.96 | 0.81 | 0.86 | 1.09 | 1.25 | 1.50 | 1.55 | 1.48 | 1.35 | 1.06 | 0.81 | 0.90 |
| RH(max-min) | 94% | 91% | 87% | 92% | 88% | 89% | 89% | 88% | 89% | 89% | 89% | 92% |
| Dlt(ETx-ETn) | 0.07 | 0.06 | 0.07 | 0.08 | 0.10 | 0.12 | 0.12 | 0.12 | 0.10 | 0.08 | 0.07 | 0.07 |
| P-atm. | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 |
| lambda | 2.48 | 2.49 | 2.48 | 2.48 | 2.47 | 2.46 | 2.46 | 2.46 | 2.47 | 2.48 | 2.49 | 2.48 |
| gamma | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 |
| rc | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 |
| ra | 67 | 122 | 104 | 86 | 77 | 106 | 82 | 104 | 104 | 92 | 111 | 65 |
| gamma* | 0.14 | 0.10 | 0.11 | 0.12 | 0.13 | 0.11 | 0.12 | 0.11 | 0.11 | 0.12 | 0.11 | 0.14 |
| dl/dl+gm* | 0.35 | 0.38 | 0.39 | 0.41 | 0.44 | 0.51 | 0.49 | 0.51 | 0.48 | 0.42 | 0.38 | 0.34 |
| gm/dl+gm* | 0.32 | 0.40 | 0.37 | 0.33 | 0.30 | 0.30 | 0.28 | 0.29 | 0.31 | 0.33 | 0.38 | 0.32 |
| Aeroterm | 0.28 | 0.23 | 0.41 | 0.39 | 0.64 | 0.55 | 0.60 | 0.61 | 0.47 | 0.44 | 0.35 | 0.37 |
| Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| dayno | 15 | 46 | 76 | 107 | 137 | 168 | 198 | 229 | 259 | 290 | 320 | 351 |
| soldeclin | -0.370 | -0.230 | -0.033 | 0.179 | 0.334 | 0.408 | 0.372 | 0.233 | 0.036 | -0.176 | -0.336 | -0.408 |
| xx | -0.281 | -0.178 | -0.026 | 0.138 | 0.255 | 0.308 | 0.282 | 0.179 | 0.028 | -0.136 | -0.256 | -0.308 |
| yy | 0.587 | 0.613 | 0.629 | 0.619 | 0.595 | 0.578 | 0.586 | 0.612 | 0.629 | 0.620 | 0.594 | 0.578 |
| omega | 1.07 | 1.28 | 1.53 | 1.80 | 2.01 | 2.13 | 2.07 | 1.87 | 1.62 | 1.35 | 1.13 | 1.01 |
| dr | 1.03 | 1.02 | 1.01 | 0.99 | 0.98 | 0.97 | 0.97 | 0.98 | 0.99 | 1.01 | 1.02 | 1.03 |
| Ra | 8.28 | 13.83 | 22.32 | 31.73 | 38.54 | 41.71 | 39.99 | 33.79 | 25.10 | 15.95 | 9.54 | 6.89 |
| N | 8.18 | 9.75 | 11.68 | 13.72 | 15.38 | 16.30 | 15.84 | 14.27 | 12.34 | 10.30 | 8.60 | 7.70 |
| Rns | 2.0 | 3.9 | 7.7 | 10.1 | 13.9 | 16.2 | 13.5 | 14.0 | 8.4 | 5.6 | 3.0 | 2.0 |
| f(n/N) | 0.22 | 0.31 | 0.45 | 0.40 | 0.49 | 0.56 | 0.44 | 0.62 | 0.43 | 0.48 | 0.39 | 0.32 |
| sigma(Tx_Tn) | 30.39 | 29.58 | 30.26 | 31.46 | 32.73 | 34.04 | 34.17 | 34.04 | 33.14 | 31.52 | 29.83 | 30.16 |
| emissivity | 0.20 | 0.21 | 0.21 | 0.20 | 0.18 | 0.17 | 0.17 | 0.17 | 0.18 | 0.20 | 0.21 | 0.21 |
| Rbo | 6.19 | 6.34 | 6.38 | 6.13 | 6.04 | 5.76 | 5.69 | 5.81 | 5.91 | 6.18 | 6.39 | 6.27 |
| LWR | 1.37 | 1.99 | 2.91 | 2.43 | 2.98 | 3.22 | 2.51 | 3.59 | 2.53 | 2.95 | 2.52 | 2.02 |
| Rn (Rns-Rl) | 0.65 | 1.93 | 4.77 | 7.69 | 10.91 | 12.98 | 11.02 | 10.39 | 5.82 | 2.68 | 0.52 | -0.04 |
| G | 0.08 | -0.27 | 0.22 | 0.39 | 0.39 | 0.39 | 0.04 | -0.04 | -0.27 | -0.50 | -0.55 | 0.11 |
| Rn-G | 0.57 | 2.20 | 4.56 | 7.30 | 10.51 | 12.59 | 10.98 | 10.43 | 6.09 | 3.18 | 1.06 | -0.15 |
| Rad Term | 0.09 | 0.30 | 0.75 | 1.27 | 1.93 | 2.69 | 2.17 | 2.14 | 1.13 | 0.45 | 0.08 | -0.01 |
| Rad Term(-G) | 0.08 | 0.34 | 0.71 | 1.21 | 1.86 | 2.61 | 2.16 | 2.15 | 1.19 | 0.54 | 0.16 | -0.02 |
| ETcomb | 0.37 | 0.53 | 1.16 | 1.66 | 2.57 | 3.24 | 2.77 | 2.75 | 1.60 | 0.89 | 0.42 | 0.36 |
|  | 2.9% | -7.7% | 2.9% | 3.8% | 2.7% | 2.5% | 0.3% | -0.3% | -3.2% | -9.4% | -19.8% | 4.2% |
| ET (-G) | 0.36 | 0.57 | 1.12 | 1.60 | 2.50 | 3.16 | 2.76 | 2.76 | 1.65 | 0.97 | 0.51 | 0.35 |

```
Grass                Alfalfa                2.21
Gamma*    Cff        Gamma*Cff               4.2% (STD)
  0.34                 0.42                 2.20
```

PENMAN-MONTEITH CALCULATIONS 1994

Key
All information in Blue has been entered by hand
Information in red is the output used for the next part of the water balance calculation

```
Give :          Station name :             BARTON ON SEA
                Latitude     :                 51.00    51.00      0.89  rad
                Altitude     :                    30  m.

Parameters :             Short Wave Rad                  a   =     0.25    b   =      0.50   alpha=
                         Albedo                       alpha  =     0.23
                         Long Wave Rad.                  a   =     0.90    b   =      0.10
                                                         al  =     0.34    bl  =    -0.139

                         Instrument height                         wind        temp Cropheight        AeroT Cff
                         AerDyn Resistance  ra * U =       206      200         190        12              900
                                                         Grass  Alfalfa
                         Canopy resistance    rc =          70       86                    12
```

|  | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tmax | 9.5 | 8.2 | 11.5 | 12.2 | 14.8 | 18.7 | 22.2 | 21.2 | 17.5 | 15.6 | 13.8 | 11.3 |
| Tmin | 4.1 | 2.1 | 5.6 | 4.4 | 8.6 | 10.4 | 13.8 | 13.7 | 10.9 | 7.7 | 9.6 | 5.3 |
| RHmean | 93 | 94 | 91 | 85 | 87 | 87 | 89 | 87 | 89 | 92 | 95 | 94 |
| RHmin | 76 | 75 | 73 | 63 | 70 | 64 | 66 | 67 | 71 | 68 | 82 | 75 |
| Wind (km/d) | 249 | 201 | 284 | 241 | 196 | 224 | 166 | 202 | 202 | 192 | 176 | 260 |
| Sunhours | 2.50 | 2.70 | 3.70 | 6.30 | 5.80 | 9.50 | 9.00 | 6.80 | 5.00 | 5.70 | 1.30 | 2.00 |
| ET fao mm/day | 0.37 | 0.54 | 1.06 | 1.95 | 2.26 | 3.28 | 3.39 | 2.78 | 1.76 | 1.02 | 0.37 | 0.41 |
| Avg Temp | 6.80 | 5.15 | 8.55 | 8.30 | 11.70 | 14.55 | 18.00 | 17.45 | 14.20 | 11.65 | 11.70 | 8.30 |
| n/N | 31% | 28% | 32% | 46% | 38% | 58% | 57% | 48% | 41% | 55% | 15% | 26% |
| Wind (m/s) | 2.88 | 2.33 | 3.29 | 2.79 | 2.27 | 2.59 | 1.92 | 2.34 | 2.34 | 2.22 | 2.04 | 3.01 |
| Ea(Tmax) | 1.19 | 1.09 | 1.36 | 1.42 | 1.68 | 2.16 | 2.68 | 2.52 | 2.00 | 1.77 | 1.58 | 1.34 |
| Ea(Tmin) | 0.82 | 0.71 | 0.91 | 0.84 | 1.12 | 1.26 | 1.58 | 1.57 | 1.30 | 1.05 | 1.20 | 0.89 |
| Ea(Tx)-Ea(Tn) | 1.00 | 0.90 | 1.13 | 1.13 | 1.40 | 1.71 | 2.13 | 2.04 | 1.65 | 1.41 | 1.39 | 1.11 |
| Edew | 0.90 | 0.81 | 0.99 | 0.89 | 1.18 | 1.38 | 1.77 | 1.68 | 1.41 | 1.21 | 1.30 | 1.00 |
| *RH(max-min)* | *93%* | *94%* | *91%* | *85%* | *87%* | *87%* | *89%* | *87%* | *89%* | *92%* | *95%* | *94%* |
| Dlt(ETx-ETn) | 0.07 | 0.06 | 0.08 | 0.08 | 0.09 | 0.11 | 0.13 | 0.13 | 0.11 | 0.09 | 0.09 | 0.08 |
| P-atm. | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 |
| lambda | 2.48 | 2.49 | 2.48 | 2.48 | 2.47 | 2.47 | 2.46 | 2.46 | 2.47 | 2.47 | 2.47 | 2.48 |
| *gamma* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* |
| rc | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 |
| ra | 72 | 89 | 63 | 74 | 91 | 80 | 107 | 88 | 88 | 93 | 101 | 68 |
| gamma* | 0.13 | 0.12 | 0.14 | 0.13 | 0.12 | 0.12 | 0.11 | 0.12 | 0.12 | 0.12 | 0.11 | 0.13 |
| dl/dl+gm* | 0.35 | 0.35 | 0.35 | 0.37 | 0.44 | 0.47 | 0.55 | 0.52 | 0.47 | 0.44 | 0.45 | 0.36 |
| gm/dl+gm* | 0.33 | 0.37 | 0.31 | 0.32 | 0.32 | 0.28 | 0.28 | 0.27 | 0.30 | 0.32 | 0.33 | 0.32 |
| Aeroterm | 0.31 | 0.24 | 0.47 | 0.68 | 0.51 | 0.76 | 0.59 | 0.71 | 0.52 | 0.45 | 0.19 | 0.34 |
| Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| dayno | 15 | 46 | 76 | 107 | 137 | 168 | 198 | 229 | 259 | 290 | 320 | 351 |
| soldeclin | -0.370 | -0.230 | -0.033 | 0.179 | 0.334 | 0.408 | 0.372 | 0.233 | 0.036 | -0.176 | -0.336 | -0.408 |
| xx | -0.281 | -0.178 | -0.026 | 0.138 | 0.255 | 0.308 | 0.282 | 0.179 | 0.028 | -0.136 | -0.256 | -0.308 |
| yy | 0.587 | 0.613 | 0.629 | 0.619 | 0.595 | 0.578 | 0.586 | 0.612 | 0.629 | 0.620 | 0.594 | 0.578 |
| omega | 1.07 | 1.28 | 1.53 | 1.80 | 2.01 | 2.13 | 2.07 | 1.87 | 1.62 | 1.35 | 1.13 | 1.01 |
| dr | *1.03* | *1.02* | *1.01* | *0.99* | *0.98* | *0.97* | *0.97* | *0.98* | *0.99* | *1.01* | *1.02* | *1.03* |
| Ra | 8.28 | 13.83 | 22.32 | 31.73 | 38.54 | 41.71 | 39.99 | 33.79 | 25.10 | 15.95 | 9.54 | 6.89 |
| N | 8.18 | 9.75 | 11.68 | 13.72 | 15.38 | 16.30 | 15.84 | 14.27 | 12.34 | 10.30 | 8.60 | 7.70 |
| Rns | 2.6 | 4.1 | 7.0 | 11.7 | 13.0 | 17.4 | 16.4 | 12.7 | 8.7 | 6.5 | 2.4 | 2.0 |
| f(n/N) | 0.38 | 0.35 | 0.38 | 0.51 | 0.44 | 0.62 | 0.61 | 0.53 | 0.46 | 0.60 | 0.24 | 0.33 |
| sigma(Tx_Tn) | 30.12 | 29.42 | 30.88 | 30.79 | 32.29 | 33.62 | 35.26 | 34.98 | 33.44 | 32.28 | 32.27 | 30.77 |
| emissivity | 0.21 | 0.21 | 0.20 | 0.21 | 0.19 | 0.18 | 0.16 | 0.16 | 0.17 | 0.19 | 0.18 | 0.20 |
| Rbo | 6.25 | 6.30 | 6.22 | 6.41 | 6.10 | 5.93 | 5.46 | 5.58 | 5.83 | 6.02 | 5.85 | 6.17 |
| LWR | 2.35 | 2.21 | 2.40 | 3.30 | 2.69 | 3.71 | 3.35 | 2.96 | 2.72 | 3.61 | 1.39 | 2.06 |
| Rn (Rns-Rl) | 0.22 | 1.93 | 4.62 | 8.42 | 10.33 | 13.67 | 13.10 | 9.75 | 6.03 | 2.86 | 1.01 | -0.05 |
| G | -0.21 | -0.23 | 0.48 | -0.04 | 0.48 | 0.40 | 0.48 | -0.08 | -0.46 | -0.36 | 0.01 | -0.48 |
| *Rn-G* | *0.43* | *2.16* | *4.14* | *8.46* | *9.85* | *13.28* | *12.62* | *9.83* | *6.49* | *3.21* | *1.00* | *0.43* |
| Rad Term | 0.03 | 0.27 | 0.66 | 1.26 | 1.84 | 2.59 | 2.91 | 2.05 | 1.15 | 0.51 | 0.18 | -0.01 |
| Rad Term(-G) | 0.06 | 0.30 | 0.59 | 1.27 | 1.75 | 2.51 | 2.80 | 2.07 | 1.24 | 0.58 | 0.18 | 0.06 |
| *ETcomb* | *0.34* | 0.51 | *1.13* | 1.94 | *2.35* | *3.35* | *3.50* | 2.76 | 1.67 | *0.96* | *0.38* | 0.34 |
|  | -8.6% | -6.3% | 6.0% | -0.3% | 3.6% | 2.3% | 3.1% | -0.6% | -5.2% | -6.7% | 0.3% | -20.6% |
| ET (-G) | 0.37 | 0.54 | 1.06 | 1.95 | 2.26 | 3.28 | 3.39 | 2.78 | 1.76 | 1.02 | 0.37 | 0.41 |

```
Grass                  Alfalfa                2.36
Gamma*    Cff          Gamma*Cff               3.7% (STD)
    0.34                   0.42               2.35
```

PENMAN-MONTEITH CALCULATIONS 1995

Key
All information in Blue has been entered by hand
Information in red is the output used for the next part of the water balance calculation

Give :
Station name : BARTON ON SEA
Latitude : 51.00 51.00 0.89 rad
Altitude : 30 m.

Parameters :
Short Wave Rad a = 0.25 b = 0.50 alpha=
Albedo alpha = 0.23
Long Wave Rad. a = 0.90 b = 0.10
al = 0.34 bl = -0.139

Instrument height wind 200 temp 190 Cropheight 12
AerDyn Resistance ra * U = 206 AeroT Cff 900
Canopy resistance rc = Grass 70 Alfalfa 86 12

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tmax | 9.2 | 10.6 | 10.7 | 13.6 | 16.7 | 20.2 | 22.8 | 25.5 | 18.5 | 17.2 | 12.4 | 6.8 |
| Tmin | 3.2 | 5.8 | 2.6 | 5.7 | 7.8 | 10.2 | 13.7 | 13.8 | 10.5 | 11.0 | 5.1 | 1.2 |
| RHmean | 91 | 91 | 84 | 85 | 81 | 84 | 88 | 87 | 89 | 92 | 92 | 92 |
| RHmin | 73 | 77 | 61 | 63 | 58 | 58 | 64 | 57 | 66 | 74 | 70 | 74 |
| Wind (km/d) | 276 | 263 | 224 | 180 | 171 | 198 | 188 | 168 | 190 | 170 | 150 | 174 |
| Sunhours | 1.70 | 2.70 | 6.20 | 6.20 | 8.70 | 8.40 | 8.50 | 9.90 | 5.70 | 3.90 | 3.00 | 1.60 |
| ET fao mm/day | 0.42 | 0.62 | 1.42 | 1.94 | 2.95 | 3.39 | 3.43 | 3.53 | 1.96 | 0.94 | 0.54 | 0.33 |
| Avg Temp | 6.20 | 8.20 | 6.65 | 9.65 | 12.25 | 15.20 | 18.25 | 19.65 | 14.50 | 14.10 | 8.75 | 4.00 |
| n/N | 21% | 28% | 53% | 45% | 57% | 52% | 54% | 69% | 46% | 38% | 35% | 21% |
| Wind (m/s) | 3.19 | 3.04 | 2.59 | 2.08 | 1.98 | 2.29 | 2.18 | 1.94 | 2.20 | 1.97 | 1.74 | 2.01 |
| Ea(Tmax) | 1.16 | 1.28 | 1.29 | 1.56 | 1.90 | 2.37 | 2.78 | 3.26 | 2.13 | 1.96 | 1.44 | 0.99 |
| Ea(Tmin) | 0.77 | 0.92 | 0.74 | 0.92 | 1.06 | 1.24 | 1.57 | 1.58 | 1.27 | 1.31 | 0.88 | 0.67 |
| Ea(Tx)-Ea(Tn) | 0.97 | 1.10 | 1.01 | 1.24 | 1.48 | 1.81 | 2.17 | 2.42 | 1.70 | 1.64 | 1.16 | 0.83 |
| Edew | 0.84 | 0.98 | 0.78 | 0.98 | 1.10 | 1.37 | 1.76 | 1.85 | 1.41 | 1.45 | 1.00 | 0.73 |
| RH(max-min) | 91% | 91% | 84% | 85% | 81% | 84% | 88% | 87% | 89% | 92% | 92% | 92% |
| Dlt(ETx-ETn) | 0.07 | 0.07 | 0.07 | 0.08 | 0.10 | 0.11 | 0.14 | 0.15 | 0.11 | 0.11 | 0.08 | 0.06 |
| P-atm. | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 |
| lambda | 2.49 | 2.48 | 2.49 | 2.48 | 2.47 | 2.47 | 2.46 | 2.45 | 2.47 | 2.47 | 2.48 | 2.49 |
| gamma | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 |
| rc | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 |
| ra | 65 | 68 | 80 | 99 | 104 | 90 | 95 | 106 | 94 | 105 | 119 | 102 |
| gamma* | 0.14 | 0.13 | 0.12 | 0.11 | 0.11 | 0.12 | 0.12 | 0.11 | 0.12 | 0.11 | 0.11 | 0.11 |
| dl/dl+gm* | 0.33 | 0.36 | 0.36 | 0.42 | 0.47 | 0.49 | 0.54 | 0.57 | 0.48 | 0.49 | 0.43 | 0.34 |
| gm/dl+gm* | 0.32 | 0.32 | 0.34 | 0.34 | 0.32 | 0.29 | 0.27 | 0.26 | 0.30 | 0.31 | 0.36 | 0.39 |
| Aeroterm | 0.41 | 0.37 | 0.65 | 0.58 | 0.76 | 0.89 | 0.73 | 0.88 | 0.59 | 0.36 | 0.32 | 0.24 |
| Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| dayno | 15 | 46 | 76 | 107 | 137 | 168 | 198 | 229 | 259 | 290 | 320 | 351 |
| soldeclin | -0.370 | -0.230 | -0.033 | 0.179 | 0.334 | 0.408 | 0.372 | 0.233 | 0.036 | -0.176 | -0.336 | -0.408 |
| xx | -0.281 | -0.178 | -0.026 | 0.138 | 0.255 | 0.308 | 0.282 | 0.179 | 0.028 | -0.136 | -0.256 | -0.308 |
| yy | 0.587 | 0.613 | 0.629 | 0.619 | 0.595 | 0.578 | 0.586 | 0.612 | 0.629 | 0.620 | 0.594 | 0.578 |
| omega | 1.07 | 1.28 | 1.53 | 1.80 | 2.01 | 2.13 | 2.07 | 1.87 | 1.62 | 1.35 | 1.13 | 1.01 |
| dr | 1.03 | 1.02 | 1.01 | 0.99 | 0.98 | 0.97 | 0.97 | 0.98 | 0.99 | 1.01 | 1.02 | 1.03 |
| Ra | 8.28 | 13.83 | 22.32 | 31.73 | 38.54 | 41.71 | 39.99 | 33.79 | 25.10 | 15.95 | 9.54 | 6.89 |
| N | 8.18 | 9.75 | 11.68 | 13.72 | 15.38 | 16.30 | 15.84 | 14.27 | 12.34 | 10.30 | 8.60 | 7.70 |
| Rns | 2.3 | 4.1 | 8.9 | 11.6 | 15.8 | 16.3 | 16.0 | 15.5 | 9.3 | 5.4 | 3.1 | 1.9 |
| f(n/N) | 0.29 | 0.35 | 0.58 | 0.51 | 0.61 | 0.56 | 0.58 | 0.72 | 0.52 | 0.44 | 0.41 | 0.29 |
| sigma(Tx_Tn) | 29.86 | 30.72 | 30.07 | 31.38 | 32.56 | 33.94 | 35.39 | 36.11 | 33.59 | 33.39 | 30.98 | 28.93 |
| emissivity | 0.21 | 0.20 | 0.22 | 0.20 | 0.19 | 0.18 | 0.16 | 0.15 | 0.17 | 0.17 | 0.20 | 0.22 |
| Rbo | 6.33 | 6.20 | 6.51 | 6.34 | 6.31 | 6.00 | 5.49 | 5.43 | 5.86 | 5.76 | 6.21 | 6.38 |
| LWR | 1.82 | 2.17 | 3.77 | 3.22 | 3.85 | 3.39 | 3.21 | 3.95 | 3.03 | 2.54 | 2.58 | 1.83 |
| Rn (Rns-Rl) | 0.44 | 1.97 | 5.09 | 8.41 | 11.96 | 12.91 | 12.76 | 11.59 | 6.27 | 2.85 | 0.54 | 0.04 |
| G | 0.31 | 0.28 | -0.22 | 0.42 | 0.36 | 0.41 | 0.43 | 0.20 | -0.72 | -0.06 | -0.75 | -0.67 |
| Rn-G | 0.13 | 1.69 | 5.30 | 7.99 | 11.59 | 12.50 | 12.33 | 11.39 | 6.99 | 2.91 | 1.29 | 0.71 |
| Rad Term | 0.06 | 0.28 | 0.73 | 1.43 | 2.25 | 2.58 | 2.79 | 2.70 | 1.23 | 0.56 | 0.09 | 0.01 |
| Rad Term(-G) | 0.02 | 0.24 | 0.76 | 1.36 | 2.18 | 2.50 | 2.70 | 2.65 | 1.37 | 0.57 | 0.22 | 0.10 |
| ETcomb | 0.46 | 0.66 | 1.39 | 2.01 | 3.01 | 3.47 | 3.52 | 3.58 | 1.82 | 0.93 | 0.41 | 0.24 |
| | 8.7% | 6.1% | -2.3% | 3.6% | 2.3% | 2.4% | 2.7% | 1.3% | -7.8% | -1.2% | -31.4% | -37.7% |
| ET (-G) | 0.42 | 0.62 | 1.42 | 1.94 | 2.95 | 3.39 | 3.43 | 3.53 | 1.96 | 0.94 | 0.54 | 0.33 |

Grass
Gamma* Cff
0.34

Alfalfa
Gamma*Cff
0.42

2.62
3.6% (STD)
2.59

PENMAN-MONTEITH CALCULATIONS 1996

Key
All information in Blue has been entered by hand
Information in red is the output used for the next part of the water balance calculation

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| Give : | Station name : | BARTON ON SEA |  |  |  |
|  | Latitude : | 51.00 | 51.00 | 0.89 | rad |
|  | Altitude : | 30 | m. |  |  |

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
| Parameters : | Short Wave Rad | a = | 0.25 | b = | 0.50 | alpha= |
|  | Albedo | alpha = | 0.23 |  |  |  |
|  | Long Wave Rad | a = | 0.90 | b = | 0.10 |  |
|  |  | al = | 0.34 | bl = | -0.139 |  |

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
| Instrument height |  |  | wind | temp | Cropheight | AeroT Cff |
| AerDyn Resistance | ra * U = | 206 | 200 | 190 | 12 | 900 |
|  |  | Grass | Alfalfa |  |  |  |
| Canopy resistance | rc = | 70 | 86 |  | 12 |  |

|  | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tmax | 7.2 | 6.6 | 8.0 | 12.2 | 13.5 | 18.9 | 20.5 | 21.0 | 17.8 | 15.5 | 10.4 | 6.3 |
| Tmin | 3.5 | -0.1 | 2.1 | 4.7 | 5.4 | 9.3 | 11.9 | 11.2 | 10.0 | 9.3 | 3.1 | 1.4 |
| RHmean | 94 | 90 | 90 | 87 | 82 | 84 | 86 | 87 | 87 | 90 | 91 | 93 |
| RHmin | 82 | 69 | 71 | 65 | 60 | 59 | 63 | 61 | 65 | 72 | 68 | 77 |
| Wind (km/d) | 250 | 208 | 179 | 145 | 254 | 162 | 187 | 173 | 173 | 213 | 211 | 181 |
| Sunhours | 1.30 | 3.90 | 2.70 | 5.20 | 6.60 | 9.90 | 8.70 | 8.80 | 5.60 | 4.50 | 3.70 | 1.90 |
| ET fao mm/day | 0.26 | 0.61 | 0.90 | 1.69 | 2.47 | 3.37 | 3.31 | 2.97 | 1.87 | 1.01 | 0.57 | 0.25 |
| Avg Temp | 5.35 | 3.25 | 5.05 | 8.45 | 9.45 | 14.10 | 16.20 | 16.10 | 13.90 | 12.40 | 6.75 | 3.85 |
| n/N | 16% | 40% | 23% | 38% | 43% | 61% | 55% | 62% | 45% | 44% | 43% | 25% |
| Wind (m/s) | 2.89 | 2.41 | 2.07 | 1.68 | 2.94 | 1.88 | 2.16 | 2.00 | 2.00 | 2.47 | 2.44 | 2.09 |
| Ea(Tmax) | 1.02 | 0.97 | 1.07 | 1.42 | 1.55 | 2.18 | 2.41 | 2.49 | 2.04 | 1.76 | 1.26 | 0.95 |
| Ea(Tmin) | 0.79 | 0.61 | 0.71 | 0.85 | 0.90 | 1.17 | 1.39 | 1.33 | 1.23 | 1.17 | 0.76 | 0.68 |
| Ea(Tx)-Ea(Tn) | 0.90 | 0.79 | 0.89 | 1.14 | 1.22 | 1.68 | 1.90 | 1.91 | 1.63 | 1.47 | 1.01 | 0.82 |
| Edew | 0.83 | 0.67 | 0.77 | 0.93 | 0.93 | 1.28 | 1.52 | 1.51 | 1.33 | 1.27 | 0.86 | 0.74 |
| *RH(max-min)* | *94%* | *90%* | *90%* | *87%* | *82%* | *84%* | *86%* | *87%* | *87%* | *90%* | *91%* | *93%* |
| Dlt(ETx-ETn) | 0.06 | 0.06 | 0.06 | 0.08 | 0.08 | 0.11 | 0.12 | 0.12 | 0.11 | 0.10 | 0.07 | 0.06 |
| P-atm. | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 |
| lambda | 2.49 | 2.49 | 2.49 | 2.48 | 2.48 | 2.47 | 2.46 | 2.46 | 2.47 | 2.47 | 2.49 | 2.49 |
| *gamma* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* |
| rc | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 |
| ra | 71 | 86 | 99 | 123 | 70 | 110 | 95 | 103 | 103 | 84 | 84 | 98 |
| gamma* | 0.13 | 0.12 | 0.11 | 0.10 | 0.13 | 0.11 | 0.12 | 0.11 | 0.11 | 0.12 | 0.12 | 0.11 |
| dl/dl+gm* | 0.32 | 0.32 | 0.36 | 0.42 | 0.38 | 0.50 | 0.51 | 0.52 | 0.49 | 0.44 | 0.36 | 0.34 |
| gm/dl+gm* | 0.34 | 0.38 | 0.38 | 0.37 | 0.31 | 0.31 | 0.28 | 0.29 | 0.31 | 0.31 | 0.35 | 0.39 |
| Aeroterm | 0.21 | 0.34 | 0.32 | 0.41 | 0.85 | 0.72 | 0.74 | 0.71 | 0.59 | 0.48 | 0.41 | 0.21 |
| Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| dayno | 15 | 46 | 76 | 107 | 137 | 168 | 198 | 229 | 259 | 290 | 320 | 351 |
| soldeclin | -0.370 | -0.230 | -0.033 | 0.179 | 0.334 | 0.408 | 0.372 | 0.233 | 0.036 | -0.176 | -0.336 | -0.408 |
| xx | -0.281 | -0.178 | -0.026 | 0.138 | 0.255 | 0.308 | 0.282 | 0.179 | 0.028 | -0.136 | -0.256 | -0.308 |
| yy | 0.587 | 0.613 | 0.629 | 0.619 | 0.595 | 0.578 | 0.586 | 0.612 | 0.629 | 0.620 | 0.594 | 0.578 |
| omega | 1.07 | 1.28 | 1.53 | 1.80 | 2.01 | 2.13 | 2.07 | 1.87 | 1.62 | 1.35 | 1.13 | 1.01 |
| dr | *1.03* | *1.02* | *1.01* | *0.99* | *0.98* | *0.97* | *0.97* | *0.98* | *0.99* | *1.01* | *1.02* | *1.03* |
| Ra | 8.28 | 13.83 | 22.32 | 31.73 | 38.54 | 41.71 | 39.99 | 33.79 | 25.10 | 15.95 | 9.54 | 6.89 |
| N | 8.18 | 9.75 | 11.68 | 13.72 | 15.38 | 16.30 | 15.84 | 14.27 | 12.34 | 10.30 | 8.60 | 7.70 |
| Rns | 2.1 | 4.8 | 6.3 | 10.7 | 13.8 | 17.8 | 16.2 | 14.5 | 9.2 | 5.8 | 3.4 | 2.0 |
| f(n/N) | 0.24 | 0.46 | 0.31 | 0.44 | 0.49 | 0.65 | 0.59 | 0.66 | 0.51 | 0.49 | 0.49 | 0.32 |
| sigma(Tx_Tn) | 29.49 | 28.63 | 29.38 | 30.85 | 31.30 | 33.42 | 34.40 | 34.36 | 33.31 | 32.61 | 30.11 | 28.87 |
| emissivity | 0.21 | 0.23 | 0.22 | 0.21 | 0.21 | 0.18 | 0.17 | 0.17 | 0.18 | 0.18 | 0.21 | 0.22 |
| Rbo | 6.27 | 6.45 | 6.40 | 6.34 | 6.43 | 6.09 | 5.80 | 5.80 | 5.98 | 5.97 | 6.34 | 6.36 |
| *LWR* | *1.53* | *2.97* | *1.97* | *2.81* | *3.14* | *3.95* | *3.45* | *3.81* | *3.05* | *2.95* | *3.10* | *2.05* |
| Rn (Rns-Rl) | 0.57 | 1.82 | 4.31 | 7.93 | 10.65 | 13.83 | 12.70 | 10.72 | 6.17 | 2.80 | 0.32 | -0.07 |
| G | 0.21 | -0.29 | 0.25 | 0.48 | 0.14 | 0.65 | 0.29 | -0.01 | -0.31 | -0.21 | -0.79 | -0.41 |
| *Rn-G* | *0.36* | *2.11* | *4.05* | *7.46* | *10.51* | *13.18* | *12.41* | *10.73* | *6.48* | *3.01* | *1.11* | *0.33* |
| Rad Term | 0.07 | 0.23 | 0.62 | 1.36 | 1.64 | 2.79 | 2.63 | 2.26 | 1.21 | 0.50 | 0.05 | -0.01 |
| Rad Term(-G) | 0.05 | 0.27 | 0.58 | 1.28 | 1.62 | 2.66 | 2.57 | 2.26 | 1.27 | 0.54 | 0.16 | 0.05 |
| *ETcomb* | *0.28* | *0.57* | *0.93* | *1.77* | *2.49* | *3.50* | *3.37* | *2.97* | *1.81* | *0.98* | *0.46* | *0.20* |
|  | 9.6% | -6.5% | 3.9% | 4.6% | 0.9% | 3.7% | 1.8% | -0.1% | -3.4% | -3.8% | -25.3% | -27.5% |
| ET (-G) | 0.26 | 0.61 | 0.90 | 1.69 | 2.47 | 3.37 | 3.31 | 2.97 | 1.87 | 1.01 | 0.57 | 0.25 |

|  |  |  |  |
|---|---|---|---|
| Grass |  | Alfalfa | 2.41 |
| Gamma* | Cff | Gamma*Cff | 3.0% (STD) |
| 0.34 |  | 0.42 | 2.39 |

PENMAN-MONTEITH CALCULATIONS 1997

Key
All information in Blue has been entered by hand
Information in red is the output used for the next part of the water balance calculation

Give : Station name : BARTON ON SEA
Latitude : 51.00 51.00 0.89 rad
Altitude : 30 m.

Parameters : Short Wave Rad a = 0.25 b = 0.50 alpha=
Albedo alpha = 0.23
*Long Wave Rad.* a = *0.90* b = *0.10*
al = 0.34 bl = -0.139

Instrument height wind temp Cropheight AeroT Cff
AerDyn Resistance ra * U = 206 200 190 12 900
Grass Alfalfa
Canopy resistance rc = 70 86 12

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tmax | 4.9 | 9.1 | 11.8 | 13.7 | 16.3 | 18.0 | 20.6 | 22.0 | 19.1 | | | |
| Tmin | -0.2 | 3.8 | 4.7 | 3.9 | 7.2 | 11.0 | 11.9 | 14.6 | 10.9 | | | |
| RHmean | 96 | 92 | 92 | 80 | 85 | 88 | 87 | 92 | 89 | | | |
| RHmin | 78 | 76 | 70 | 55 | 60 | 68 | 64 | 71 | 66 | 0 | 0 | 0 |
| Wind (km/d) | 160 | 277 | 162 | 170 | 202 | 198 | 158 | 160 | 141 | | | |
| Sunhours | 1.60 | 2.20 | 4.70 | 8.60 | 9.00 | 5.60 | 9.40 | 5.90 | 7.20 | | | |
| ET fao mm/day | 0.15 | 0.54 | 1.09 | 2.30 | 2.84 | 2.67 | 3.38 | 2.47 | 2.02 | #DIV/0! | #DIV/0! | #DIV/0! |
| Avg Temp | 2.35 | 6.45 | 8.25 | 8.80 | 11.75 | 14.50 | 16.25 | 18.30 | 15.00 | 0.00 | 0.00 | 0.00 |
| n/N | 20% | 23% | 40% | 63% | 59% | 34% | 59% | 41% | 58% | 0% | 0% | 0% |
| Wind (m/s) | 1.85 | 3.21 | 1.88 | 1.97 | 2.34 | 2.29 | 1.83 | 1.85 | 1.63 | 0.00 | 0.00 | 0.00 |
| Ea(Tmax) | 0.87 | 1.16 | 1.38 | 1.57 | 1.85 | 2.06 | 2.43 | 2.64 | 2.21 | 0.61 | 0.61 | 0.61 |
| Ea(Tmin) | 0.60 | 0.80 | 0.85 | 0.81 | 1.02 | 1.31 | 1.39 | 1.66 | 1.30 | 0.61 | 0.61 | 0.61 |
| Ea(Tx)-Ea(Tn) | 0.73 | 0.98 | 1.12 | 1.19 | 1.43 | 1.69 | 1.91 | 2.15 | 1.76 | 0.61 | 0.61 | 0.61 |
| Edew | 0.68 | 0.87 | 0.97 | 0.86 | 1.11 | 1.41 | 1.55 | 1.88 | 1.45 | 0.00 | 0.00 | 0.00 |
| *RH(max-min)* | *96%* | *92%* | *92%* | *80%* | *85%* | *88%* | *87%* | *92%* | *89%* | *0%* | *0%* | *0%* |
| Dlt(ETx-ETn) | 0.05 | 0.07 | 0.08 | 0.08 | 0.09 | 0.11 | 0.12 | 0.13 | 0.11 | 0.04 | 0.04 | 0.04 |
| P-atm. | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 | 100.9 |
| lambda | 2.50 | 2.49 | 2.48 | 2.48 | 2.47 | 2.47 | 2.46 | 2.46 | 2.47 | 2.50 | 2.50 | 2.50 |
| gamma | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* | *0.07* |
| rc | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 |
| ra | 111 | 64 | 110 | 105 | 88 | 90 | 113 | 111 | 126 | #DIV/0! | #DIV/0! | #DIV/0! |
| gamma* | 0.11 | 0.14 | 0.11 | 0.11 | 0.12 | 0.12 | 0.11 | 0.11 | 0.10 | #DIV/0! | #DIV/0! | #DIV/0! |
| dl/dl+gm* | 0.33 | 0.33 | 0.41 | 0.42 | 0.44 | 0.48 | 0.53 | 0.55 | 0.52 | #DIV/0! | #DIV/0! | #DIV/0! |
| gm/dl+gm* | 0.41 | 0.32 | 0.36 | 0.35 | 0.31 | 0.29 | 0.29 | 0.28 | 0.31 | #DIV/0! | #DIV/0! | #DIV/0! |
| Aeroterm | 0.14 | 0.35 | 0.33 | 0.73 | 0.74 | 0.58 | 0.61 | 0.42 | 0.48 | #DIV/0! | #DIV/0! | #DIV/0! |
| Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| dayno | 15 | 46 | 76 | 107 | 137 | 168 | 198 | 229 | 259 | 290 | 320 | 351 |
| soldeclin | -0.370 | -0.230 | -0.033 | 0.179 | 0.334 | 0.408 | 0.372 | 0.233 | 0.036 | -0.176 | -0.336 | -0.408 |
| xx | -0.281 | -0.178 | -0.026 | 0.138 | 0.255 | 0.308 | 0.282 | 0.179 | 0.028 | -0.136 | -0.256 | -0.308 |
| yy | 0.587 | 0.613 | 0.629 | 0.619 | 0.595 | 0.578 | 0.586 | 0.612 | 0.629 | 0.620 | 0.594 | 0.578 |
| omega | 1.07 | 1.28 | 1.53 | 1.80 | 2.01 | 2.13 | 2.07 | 1.87 | 1.62 | 1.35 | 1.13 | 1.01 |
| dr | *1.03* | *1.02* | *1.01* | *0.99* | *0.98* | *0.97* | *0.97* | *0.98* | *0.99* | *1.01* | *1.02* | *1.03* |
| Ra | 8.28 | 13.83 | 22.32 | 31.73 | 38.54 | 41.71 | 39.99 | 33.79 | 25.10 | 15.95 | 9.54 | 6.89 |
| N | 8.18 | 9.75 | 11.68 | 13.72 | 15.38 | 16.30 | 15.84 | 14.27 | 12.34 | 10.30 | 8.60 | 7.70 |
| Rns | 2.2 | 3.9 | 7.8 | 13.8 | 16.1 | 13.5 | 16.8 | 11.9 | 10.5 | 3.1 | 1.8 | 1.3 |
| f(n/N) | 0.28 | 0.30 | 0.46 | 0.66 | 0.63 | 0.41 | 0.63 | 0.47 | 0.63 | 0.10 | 0.10 | 0.10 |
| sigma(Tx_Tn) | 28.25 | 29.97 | 30.76 | 31.03 | 32.34 | 33.58 | 34.42 | 35.39 | 33.83 | 27.28 | 27.28 | 27.28 |
| emissivity | 0.23 | 0.21 | 0.20 | 0.21 | 0.19 | 0.17 | 0.17 | 0.15 | 0.17 | 0.34 | 0.34 | 0.34 |
| Rbo | 6.35 | 6.28 | 6.24 | 6.54 | 6.24 | 5.86 | 5.74 | 5.27 | 5.82 | 9.25 | 9.25 | 9.25 |
| *LWR* | 1.76 | 1.91 | *2.89* | 4.35 | *3.92* | 2.40 | *3.65* | 2.49 | 3.65 | 0.93 | 0.93 | 0.93 |
| Rn (Rns-Rl) | 0.46 | 1.96 | 4.86 | 9.41 | 12.18 | 11.14 | 13.19 | 9.39 | 6.83 | 2.14 | 0.91 | 0.40 |
| G | 0.33 | 0.57 | 0.25 | 0.08 | 0.41 | 0.39 | 0.25 | 0.29 | -0.46 | -2.10 | 0.00 | 0.00 |
| *Rn-G* | *0.13* | *1.38* | *4.61* | *9.34* | *11.77* | *10.76* | *12.94* | 9.10 | 7.29 | 4.24 | *0.91* | *0.40* |
| Rad Term | 0.06 | 0.26 | 0.81 | 1.59 | 2.17 | 2.16 | 2.83 | 2.11 | 1.44 | #DIV/0! | #DIV/0! | #DIV/0! |
| Rad Term(-G) | 0.02 | 0.18 | 0.76 | 1.58 | 2.10 | 2.09 | 2.77 | 2.05 | 1.54 | #DIV/0! | #DIV/0! | #DIV/0! |
| *ETcomb* | *0.20* | *0.61* | *1.13* | *2.31* | 2.91 | 2.74 | 3.43 | 2.53 | 1.92 | #DIV/0! | #DIV/0! | #DIV/0! |
| | 21.9% | 12.4% | 3.7% | 0.6% | 2.5% | 2.7% | 1.5% | 2.5% | -5.1% | #DIV/0! | #DIV/0! | #DIV/0! |
| ET (-G) | 0.15 | 0.54 | 1.09 | 2.30 | 2.84 | 2.67 | 3.38 | 2.47 | 2.02 | #DIV/0! | #DIV/0! | #DIV/0! |

| | | |
|---|---|---|
| Grass | Alfalfa | #DIV/0! |
| Gamma* Cff | Gamma*Cff | #DIV/0! (STD) |
| 0.34 | 0.42 | #DIV/0! |

## CALCULATION BREAKDOWN FOR EACH YEAR OF ESTIMATES FOR THE EFFECTIVE RAINFALL

| **1990** | Actual Rainfall | Potential Evapotranspiration. | The Lower | Estimate of Soil Moisture Deficit | Estimate of Evapotranspiration | Effective Rainfall |
|---|---|---|---|---|---|---|
| Jan | 112.7 | 11.0 | 11.0 | 100.0 | 11.0 | 101.7 |
| Feb | 166.5 | 20.2 | 20.2 | 100.0 | 20.2 | 146.3 |
| Mar | 6.4 | 39.9 | 6.4 | 100.0 | 6.4 | 0.0 |
| Apr | 43.9 | 68.2 | 43.9 | 80.0 | 35.1 | 8.8 |
| May | 11.2 | 96.3 | 11.2 | 60.0 | 6.7 | 4.5 |
| Jun | 55.3 | 76.0 | 55.3 | 20.0 | 11.1 | 44.2 |
| Jul | 12.2 | 115.0 | 12.2 | 50.0 | 6.1 | 6.1 |
| Aug | 23.1 | 97.3 | 23.1 | 60.0 | 13.9 | 9.2 |
| Sep | 28.9 | 64.3 | 28.9 | 70.0 | 20.2 | 8.7 |
| Oct | 98.6 | 31.9 | 31.9 | 80.0 | 25.5 | 73.1 |
| Nov | 53.6 | 14.1 | 14.1 | 100.0 | 14.1 | 39.5 |
| Dec | 62.3 | 11.0 | 11.0 | 100.0 | 11.0 | 51.3 |
| Totals | 674.7 | 645.4 | | | | 493.3 |

| **1991** | Actual Rainfall | Potential Evapotranspiration. | The Lower | Estimate of Soil Moisture Deficit | Estimate of Evapotranspiration | Effective Rainfall |
|---|---|---|---|---|---|---|
| Jan | 88.5 | 11.3 | 11.3 | 100.0 | 11.3 | 77.2 |
| Feb | 29.3 | 13.3 | 13.3 | 100.0 | 13.3 | 16.0 |
| Mar | 77.9 | 28.8 | 28.8 | 100.0 | 28.8 | 49.1 |
| Apr | 42.3 | 55.9 | 42.3 | 80.0 | 33.8 | 8.5 |
| May | 4.0 | 75.0 | 4.0 | 60.0 | 2.4 | 1.6 |
| Jun | 113.0 | 72.6 | 72.6 | 20.0 | 14.5 | 98.5 |
| Jul | 63.3 | 88.3 | 63.3 | 50.0 | 31.7 | 31.7 |
| Aug | 12.3 | 87.8 | 12.3 | 60.0 | 7.4 | 4.9 |
| Sep | 48.6 | 57.1 | 48.6 | 70.0 | 34.0 | 14.6 |
| Oct | 63.0 | 28.4 | 28.4 | 80.0 | 22.7 | 40.3 |
| Nov | 49.2 | 16.0 | 16.0 | 100.0 | 16.0 | 33.2 |
| Dec | 33.4 | 9.8 | 9.8 | 100.0 | 9.8 | 23.6 |
| Totals | 624.8 | 544.4 | | | | 399.1 |

| **1992** | Actual Rainfall | Potential Evapotranspiration. | The Lower | Estimate of Soil Moisture Deficit | Estimate of Evapotranspiration | Effective Rainfall |
|---|---|---|---|---|---|---|
| Jan | 21.7 | 7.8 | 7.8 | 100.0 | 7.8 | 13.9 |
| Feb | 28.6 | 18.7 | 18.7 | 100.0 | 18.7 | 9.9 |
| Mar | 51.6 | 31.7 | 31.7 | 100.0 | 31.7 | 19.9 |
| Apr | 70.4 | 54.4 | 54.4 | 80.0 | 43.5 | 26.9 |
| May | 19.6 | 94.3 | 19.6 | 60.0 | 11.8 | 7.8 |
| Jun | 32.2 | 101.5 | 32.2 | 20.0 | 6.4 | 25.8 |
| Jul | 63.1 | 84.0 | 63.1 | 50.0 | 31.6 | 31.6 |
| Aug | 88.1 | 69.8 | 69.8 | 60.0 | 41.9 | 46.2 |
| Sep | 78.9 | 49.8 | 49.8 | 70.0 | 34.9 | 44.0 |
| Oct | 81.5 | 31.7 | 31.7 | 80.0 | 25.4 | 56.1 |
| Nov | 145.3 | 14.2 | 14.2 | 100.0 | 14.2 | 131.1 |
| Dec | 81.2 | 9.8 | 9.8 | 100.0 | 9.8 | 71.4 |
| Totals | 762.2 | 567.7 | | | | 484.6 |

| **1993** | Actual Rainfall | Potential Evapotranspiration. | The Lower | Estimate of Soil Moisture Deficit | Estimate of Evapotranspiration | Effective Rainfall |
|---|---|---|---|---|---|---|
| Jan | 98.0 | 11.3 | 11.3 | 100.0 | 11.3 | 86.7 |
| Feb | 6.2 | 15.8 | 6.2 | 100.0 | 6.2 | 0.0 |
| Mar | 45.2 | 34.8 | 34.8 | 100.0 | 34.8 | 10.4 |
| Apr | 74.7 | 47.9 | 47.9 | 80.0 | 38.3 | 36.4 |
| May | 45.1 | 77.5 | 45.1 | 60.0 | 27.1 | 18.0 |
| Jun | 61.6 | 94.7 | 61.6 | 20.0 | 12.3 | 49.3 |
| Jul | 86.2 | 85.6 | 85.6 | 50.0 | 42.8 | 43.4 |
| Aug | 35.8 | 85.4 | 35.8 | 60.0 | 21.5 | 14.3 |
| Sep | 120.7 | 49.5 | 49.5 | 70.0 | 34.7 | 86.0 |
| Oct | 169.3 | 30.2 | 30.2 | 80.0 | 24.1 | 145.2 |
| Nov | 64.4 | 15.2 | 15.2 | 100.0 | 15.2 | 49.2 |
| Dec | 185.0 | 10.7 | 10.7 | 100.0 | 10.7 | 174.3 |
| Totals | 992.2 | 558.8 | | | | 713.1 |

| **1994** | Actual Rainfall | Potential Evapotranspiration. | The Lower | Estimate of Soil Moisture Deficit | Estimate of Evapotranspiration | Effective Rainfall |
|---|---|---|---|---|---|---|
| Jan | 132.2 | 11.4 | 11.4 | 100.0 | 11.4 | 120.8 |
| Feb | 89.4 | 15.1 | 15.1 | 100.0 | 15.1 | 74.3 |
| Mar | 57.8 | 33.0 | 33.0 | 100.0 | 33.0 | 24.8 |
| Apr | 61.3 | 58.4 | 58.4 | 80.0 | 46.7 | 14.6 |
| May | 81.7 | 70.2 | 70.2 | 60.0 | 42.1 | 39.6 |
| Jun | 23.4 | 98.3 | 23.4 | 20.0 | 4.7 | 18.7 |
| Jul | 19.6 | 105.1 | 19.6 | 50.0 | 9.8 | 9.8 |
| Aug | 47.6 | 86.0 | 47.6 | 60.0 | 28.6 | 19.0 |
| Sep | 70.9 | 52.8 | 52.8 | 70.0 | 37.0 | 33.9 |
| Oct | 125.8 | 31.8 | 31.8 | 80.0 | 25.4 | 100.4 |
| Nov | 91.4 | 11.2 | 11.2 | 100.0 | 11.2 | 80.2 |
| Dec | 116.9 | 12.6 | 12.6 | 100.0 | 12.6 | 104.3 |
| Totals | 918.0 | 586.0 | | | | 640.4 |

| **1995** | Actual Rainfall | Potential Evapotranspiration. | The Lower | Estimate of Soil Moisture Deficit | Estimate of Evapotranspiration | Effective Rainfall |
|---|---|---|---|---|---|---|
| Jan | 143.8 | 13.2 | 13.2 | 100.0 | 13.2 | 130.6 |
| Feb | 116.8 | 17.2 | 17.2 | 100.0 | 17.2 | 99.6 |
| Mar | 40.2 | 43.9 | 40.2 | 100.0 | 40.2 | 0.0 |
| Apr | 27.1 | 58.3 | 27.1 | 80.0 | 21.7 | 5.4 |
| May | 22.2 | 91.3 | 22.2 | 60.0 | 13.3 | 8.9 |
| Jun | 10.1 | 101.6 | 10.1 | 20.0 | 2.0 | 8.1 |
| Jul | 26.7 | 106.3 | 26.7 | 50.0 | 13.4 | 13.4 |
| Aug | 3.4 | 109.5 | 3.4 | 60.0 | 2.0 | 1.4 |
| Sep | 142.9 | 58.9 | 58.9 | 70.0 | 41.2 | 101.7 |
| Oct | 38.6 | 29.1 | 29.1 | 80.0 | 23.3 | 15.3 |
| Nov | 144.3 | 16.2 | 16.2 | 100.0 | 16.2 | 128.1 |
| Dec | 81.7 | 10.4 | 10.4 | 100.0 | 10.4 | 71.3 |
| | 797.8 | 655.9 | | | | 583.8 |

| **1996** | Actual Rainfall | Potential Evapotranspiration. | The Lower | Estimate of Soil Moisture Deficit | Estimate of Evapotranspiration | Effective Rainfall |
|---|---|---|---|---|---|---|
| Jan | 58.3 | 8.0 | 8.0 | 100.0 | 8.0 | 50.3 |
| Feb | 95.2 | 17.7 | 17.7 | 100.0 | 17.7 | 77.5 |
| Mar | 36.5 | 27.8 | 27.8 | 100.0 | 27.8 | 8.7 |
| Apr | 36.2 | 50.7 | 36.2 | 80.0 | 29.0 | 7.2 |
| May | 58.7 | 76.6 | 58.7 | 60.0 | 35.2 | 23.5 |
| Jun | 26.7 | 101.2 | 26.7 | 20.0 | 5.3 | 21.4 |
| Jul | 15.4 | 102.6 | 15.4 | 50.0 | 7.7 | 7.7 |
| Aug | 76.7 | 92.2 | 76.7 | 60.0 | 46.0 | 30.7 |
| Sep | 45.3 | 56.0 | 45.3 | 70.0 | 31.7 | 13.6 |
| Oct | 58.5 | 31.4 | 31.4 | 80.0 | 25.1 | 33.4 |
| Nov | 132.0 | 17.2 | 17.2 | 100.0 | 17.2 | 114.8 |
| Dec | 34.0 | 7.9 | 7.9 | 100.0 | 7.9 | 26.1 |
| Totals | 673.5 | 589.4 | | | | 414.8 |

| **1997** | Actual Rainfall | Potential Evapotranspiration. | The Lower | Estimate of Soil Moisture Deficit | Estimate of Evapotranspiration | Effective Rainfall |
|---|---|---|---|---|---|---|
| Jan | 17.2 | 4.8 | 4.8 | 100.0 | 4.8 | 12.4 |
| Feb | 82.2 | 15.0 | 15.0 | 100.0 | 15.0 | 67.2 |
| Mar | 32.0 | 33.9 | 32.0 | 100.0 | 32.0 | 0.0 |
| Apr | 13.2 | 69.0 | 13.2 | 80.0 | 10.6 | 2.6 |
| May | 34.5 | 88.0 | 34.5 | 60.0 | 20.7 | 13.8 |
| Jun | 75.8 | 80.1 | 75.8 | 20.0 | 15.2 | 60.6 |
| Jul | 13.2 | 104.8 | 13.2 | 50.0 | 6.6 | 6.6 |
| Aug | 84.1 | 76.6 | 76.6 | 60.0 | 45.9 | 38.2 |
| Sep | 11.9 | 60.5 | 11.9 | 70.0 | 8.3 | 3.6 |
| Oct | | | | | | |
| Nov | | | | | | |
| Dec | | | | | | |
| Totals | | | | | | |

# APPENDIX B

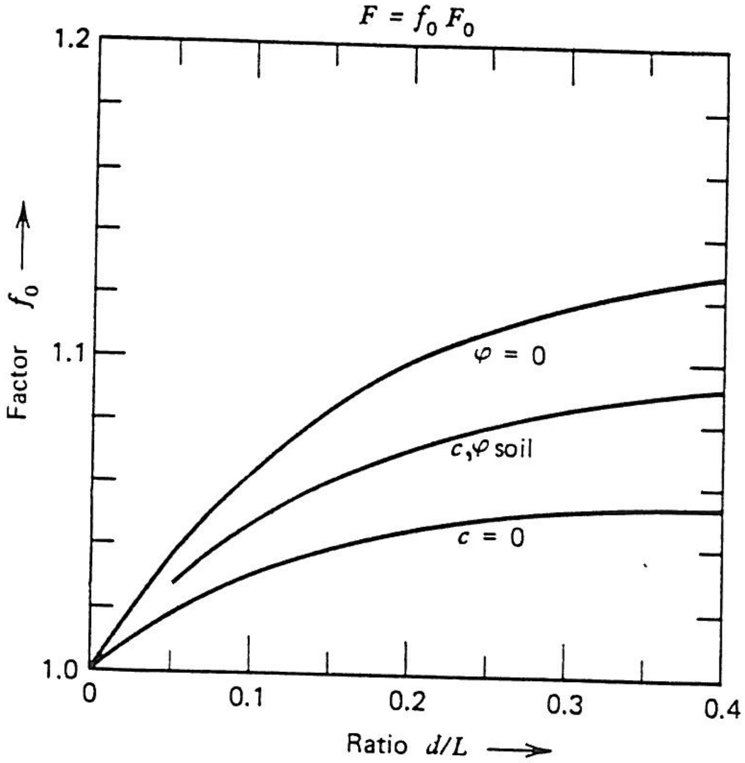
Graph of d/L Vs CF

Janbu's Interslices Sheets 1-3

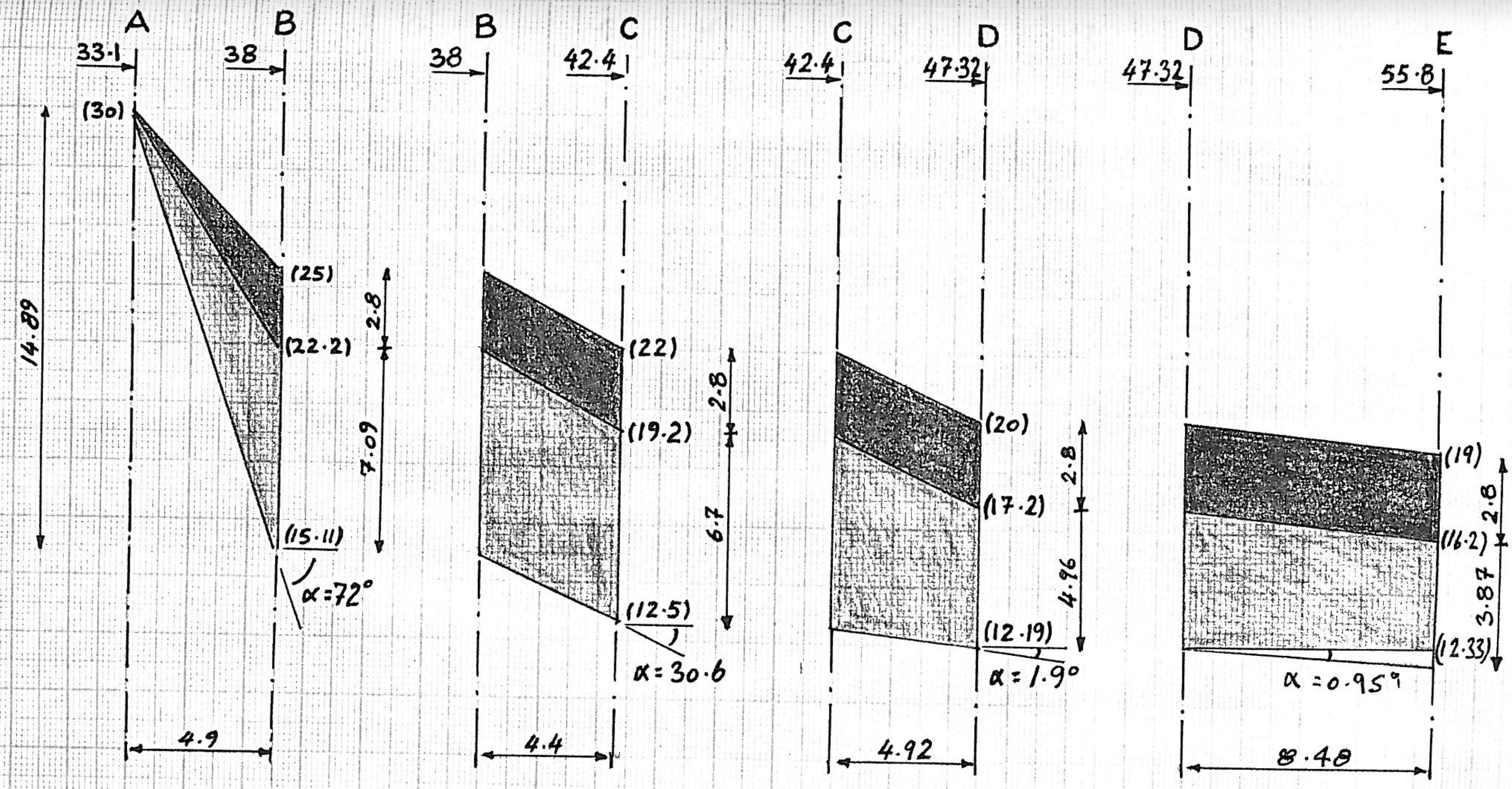
Failure Mode 1: Front Slope

Failure Mode 2 : Entire Slope

Flownet Calculations : Case 1 & 2



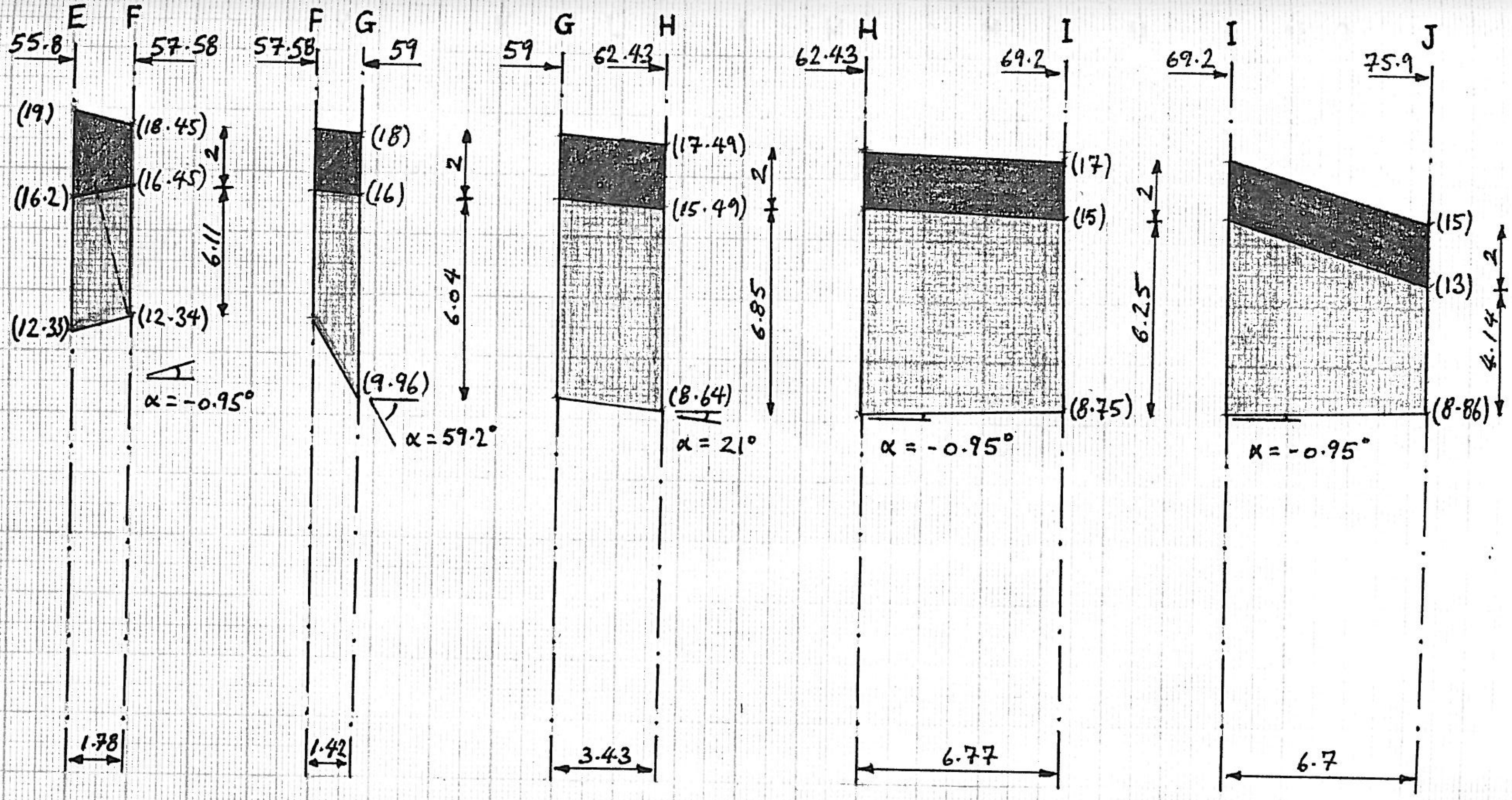
Correction factor $f_0$ as function of curvature ratio $d/L$ and type of soil.



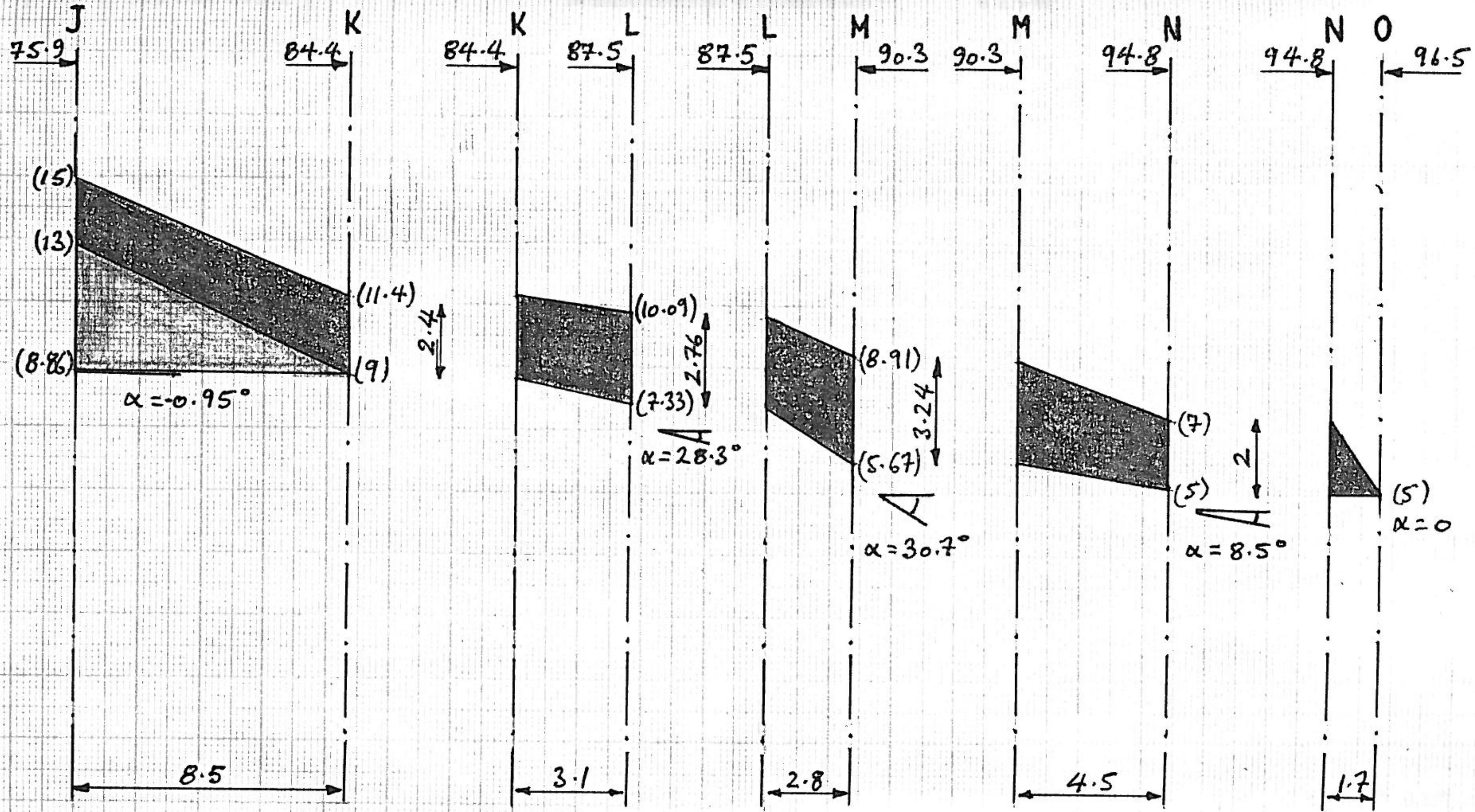
▨ MED. DENSE GRAVEL

▨ SOFT SANDY SILT

INTERSLICES FOR POINTS A-E



INTERSLICES FOR POINTS E - J



INTERSLICES FOR POINTS J-O

SHEET 3 OF 3

| Soil Type | Bulk Unit Weight of Soil Strata | |
|---|---|---|
| 1 | 20.00 | $KN/m^3$ |
| 2 | 20.00 | $KN/m^3$ |
| 3 | 20.00 | $KN/m^3$ |

**Drained cohesion of cohesive soil =** **0** ***KN/m***$^2$

**Slipped mass =** **4359.4** ***KN/m***

| Slice No. | Width of Slice 'b' (*m*) | Alpha 'a' (*Degrees*) | Soil Type 1 | | | Soil Type 2 | | | Soil Type 3 | | | Total Soil Weight 'W (*KN/m*) | tan a | Slice Phi' (*Degrees*) | tan Phi' |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ht. of Slice 1 | | wt. 1 | Ht. of Slice 2 | | wt. 2 | Ht. of Slice 3 | | wt. 3 | | | | |
| | | | LH | RH | (*KN/m*) | LH | RH | (*KN/m*) | LH | RH | (*KN/m*) | | | | |
| 1 | 1.78 | 75.00 | 1.40 | 2.00 | 60.52 | 0 | 4.11 | 73.158 | | | 0.00 | 133.68 | 3.732 | | ######## |
| 2 | 1.42 | 59.20 | 2.00 | 2.00 | 56.80 | 4.11 | 6.04 | 144.13 | | | 0 | 200.93 | 1.678 | 30 | 0.577 |
| 3 | 3.43 | 21.00 | 2.00 | 2.00 | 137.20 | 6.04 | 6.85 | 442.13 | | | 0 | 579.33 | 0.384 | 30 | 0.577 |
| 4 | 6.77 | -0.95 | 2.00 | 2.00 | 270.80 | 6.85 | 6.25 | 886.87 | | | 0 | 1157.67 | -0.017 | | ######## |
| 5 | 6.70 | -0.95 | 2.00 | 2.00 | 268.00 | 6.25 | 4.14 | 696.13 | | | 0 | 964.13 | -0.017 | | ######## |
| 6 | 8.50 | -0.95 | 2.00 | 2.40 | 374.00 | 4.14 | 0 | 351.90 | | | 0 | 725.90 | -0.017 | | ######## |
| 7 | 3.10 | 28.30 | 2.40 | 2.76 | 159.96 | | | 0 | | | 0 | 159.96 | 0.538 | 30 | 0.577 |
| 8 | 2.80 | 30.70 | 2.76 | 3.24 | 168.00 | | | 0 | | | 0 | 168.00 | 0.594 | 30 | 0.577 |
| 9 | 4.50 | 8.50 | 3.24 | 2.00 | 235.80 | | | 0 | | | 0 | 235.80 | 0.149 | 30 | 0.577 |
| 10 | 1.70 | -0.05 | 2.00 | 0 | 34.00 | | | 0 | | | 0 | 34.00 | -0.001 | 30 | 0.577 |

## Phi' changed for slip surfaces - Chama Bed & 'F' plain

| ru = | 0.1 | 0.15 | 0.2 | 0.25 | 0.3 | 0.35 | 0.4 | 0.45 | 0.5 | 0.55 | 0.6 | 0.65 | 0.7 | 0.75 | 0.8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Phi' = 12** | **1.405** | **1.312** | **1.220** | **1.128** | **1.037** | **0.946** | **0.856** | **0.767** | **0.679** | **0.593** | **0.508** | **0.426** | **0.347** | **0.271** | **0.200** |
| **Phi' = 13** | **1.467** | **1.370** | **1.274** | **1.179** | **1.084** | **0.989** | **0.896** | **0.803** | **0.712** | **0.622** | **0.534** | **0.449** | **0.366** | **0.287** | **0.213** |
| **Phi' = 14** | **1.528** | **1.428** | **1.328** | **1.229** | **1.130** | **1.032** | **0.935** | **0.840** | **0.745** | **0.652** | **0.561** | **0.471** | **0.385** | **0.303** | **0.226** |
| **Phi' = 18** | **1.774** | **1.659** | **1.545** | **1.431** | **1.318** | **1.206** | **1.095** | **0.985** | **0.876** | **0.769** | **0.664** | **0.562** | **0.462** | **0.367** | **0.277** |
| **Phi' = 24** | **2.154** | **2.016** | **1.879** | **1.742** | **1.607** | **1.473** | **1.339** | **1.207** | **1.077** | **0.948** | **0.822** | **0.699** | **0.579** | **0.464** | **0.354** |

FAILURE MODE 1: FRONT SLOPE

**c' =** 0
**fo =** 1.054

**Chama & 'F' Plain:** **Phi' =** 12
**tan phi' =** 0.212557

**Numerator** = (c'b + W (1-ru) tan phi ) {(1+ tan$^2$ a)/(1+ tan a tan phi / F)}
**Denominator** = W TAN a

| | | a | b | c | d | e | f | g | h | i | j | k | l | m | n | o |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ru = | | **0.1** | **0.15** | **0.2** | **0.25** | **0.3** | **0.35** | **0.4** | **0.45** | **0.5** | **0.55** | **0.6** | **0.65** | **0.7** | **0.75** | **0.8** |
| F = | | **1.405** | **1.312** | **1.220** | **1.128** | **1.037** | **0.946** | **0.856** | **0.767** | **0.679** | **0.593** | **0.508** | **0.426** | **0.347** | **0.271** | **0.200** |
| **SLICE No.** | **Denom.** | **Numerator** | | | | | | | | | | | | | | |
| 1 | 498.89 | 243.99 | 224.69 | 205.63 | 186.78 | 168.23 | 149.96 | 132.09 | 114.68 | 97.81 | 81.65 | 66.24 | 51.87 | 38.72 | 27.00 | 17.08 |
| 2 | 337.06 | 235.72 | 216.37 | 197.32 | 178.54 | 160.15 | 142.11 | 124.55 | 107.55 | 91.18 | 75.61 | 60.89 | 47.31 | 35.01 | 24.18 | 15.15 |
| 3 | 222.38 | 298.33 | 279.06 | 259.81 | 240.56 | 221.33 | 202.10 | 182.90 | 163.75 | 144.66 | 125.71 | 106.88 | 88.35 | 70.26 | 52.78 | 36.41 |
| 4 | -19.20 | 222.08 | 209.78 | 197.48 | 185.18 | 172.88 | 160.59 | 148.29 | 136.00 | 123.71 | 111.42 | 99.14 | 86.87 | 74.60 | 62.35 | 50.11 |
| 5 | -15.99 | 184.95 | 174.71 | 164.47 | 154.22 | 143.98 | 133.74 | 123.50 | 113.26 | 103.03 | 92.80 | 82.57 | 72.34 | 62.13 | 51.92 | 41.73 |
| 6 | -12.04 | 139.25 | 131.54 | 123.83 | 116.12 | 108.40 | 100.69 | 92.99 | 85.28 | 77.57 | 69.87 | 62.17 | 54.47 | 46.78 | 39.09 | 31.42 |
| 7 | 86.13 | 87.79 | 81.86 | 75.95 | 70.04 | 64.16 | 58.28 | 52.43 | 46.62 | 40.86 | 35.17 | 29.56 | 24.10 | 18.85 | 13.87 | 9.33 |
| 8 | 99.75 | 94.91 | 88.41 | 81.93 | 75.46 | 69.02 | 62.59 | 56.21 | 49.87 | 43.59 | 37.41 | 31.33 | 25.44 | 19.80 | 14.48 | 9.67 |
| 9 | 35.24 | 118.01 | 111.00 | 103.99 | 96.97 | 89.94 | 82.91 | 75.86 | 68.81 | 61.74 | 54.68 | 47.59 | 40.51 | 33.44 | 26.39 | 19.45 |
| 10 | -0.03 | 17.67 | 16.69 | 15.71 | 14.73 | 13.75 | 12.77 | 11.78 | 10.80 | 9.82 | 8.84 | 7.86 | 6.88 | 5.90 | 4.92 | 3.94 |
| **Totals:** | 1232.21 | 1642.72 | 1534.11 | 1426.12 | 1318.60 | 1211.84 | 1105.73 | 1000.61 | 896.63 | 793.98 | 693.16 | 594.23 | 498.14 | 405.48 | 316.98 | 234.28 |
| **FOS** | | **1.405** | **1.312** | **1.220** | **1.128** | **1.037** | **0.946** | **0.856** | **0.767** | **0.679** | **0.593** | **0.508** | **0.426** | **0.347** | **0.271** | **0.200** |

FAILURE MODE 1: FRONT SLOPE - PHI' = 12°

c' = 0
fo = 1.054

**Chama & 'F' Plain:** **Phi' =** 13
**tan phi' =** 0.230868

**Numerator** = (c'b + W (1-ru) tan phi ) {(1+ $\tan^2$ a)/(1+ tan a tan phi / F)}
**Denominator** = W TAN a

| | | a | b | c | d | e | f | g | h | i | j | k | l | m | n | o |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **ru =** | **0.1** | **0.15** | **0.2** | **0.25** | **0.3** | **0.35** | **0.4** | **0.45** | **0.5** | **0.55** | **0.6** | **0.65** | **0.7** | **0.75** | **0.8** |
| | **F =** | **1.467** | **1.370** | **1.274** | **1.179** | **1.084** | **0.989** | **0.896** | **0.803** | **0.712** | **0.622** | **0.534** | **0.449** | **0.366** | **0.287** | **0.213** |
| **SLICE No.** | **Denom.** | **Numerator** | | | | | | | | | | | | | | |
| 1 | 498.89 | 261.22 | 240.41 | 219.87 | 199.64 | 179.68 | 160.04 | 140.92 | 122.24 | 104.23 | 86.92 | 70.51 | 55.24 | 41.21 | 28.78 | 18.26 |
| 2 | 337.06 | 239.86 | 220.33 | 201.09 | 182.18 | 163.57 | 145.30 | 127.57 | 110.31 | 93.73 | 77.86 | 62.90 | 49.05 | 36.40 | 25.29 | 15.95 |
| 3 | 222.38 | 300.05 | 280.78 | 261.52 | 242.28 | 223.03 | 203.78 | 184.60 | 165.41 | 146.33 | 127.32 | 108.48 | 89.93 | 71.71 | 54.14 | 37.61 |
| 4 | -19.20 | 241.24 | 227.88 | 214.52 | 201.16 | 187.80 | 174.45 | 161.09 | 147.74 | 134.39 | 121.05 | 107.71 | 94.37 | 81.05 | 67.74 | 54.45 |
| 5 | -15.99 | 200.91 | 189.78 | 178.66 | 167.53 | 156.41 | 145.28 | 134.16 | 123.04 | 111.93 | 100.81 | 89.70 | 78.60 | 67.50 | 56.41 | 45.34 |
| 6 | -12.04 | 151.26 | 142.89 | 134.51 | 126.13 | 117.76 | 109.39 | 101.01 | 92.64 | 84.27 | 75.90 | 67.54 | 59.18 | 50.82 | 42.47 | 34.14 |
| 7 | 86.13 | 88.47 | 82.53 | 76.61 | 70.70 | 64.80 | 58.91 | 53.07 | 47.23 | 41.46 | 35.74 | 30.12 | 24.64 | 19.32 | 14.30 | 9.69 |
| 8 | 99.75 | 95.71 | 89.19 | 82.70 | 76.23 | 69.77 | 63.32 | 56.93 | 50.57 | 44.28 | 38.06 | 31.96 | 26.04 | 20.32 | 14.95 | 10.06 |
| 9 | 35.24 | 118.30 | 111.29 | 104.28 | 97.27 | 90.24 | 83.21 | 76.17 | 69.12 | 62.07 | 55.00 | 47.93 | 40.86 | 33.79 | 26.75 | 19.81 |
| 10 | -0.03 | 17.67 | 16.69 | 15.71 | 14.73 | 13.75 | 12.77 | 11.78 | 10.80 | 9.82 | 8.84 | 7.86 | 6.88 | 5.90 | 4.92 | 3.94 |
| **Totals:** | 1232.21 | 1714.69 | 1601.77 | 1489.46 | 1377.85 | 1266.82 | 1156.45 | 1047.31 | 939.11 | 832.51 | 727.52 | 624.71 | 524.78 | 428.02 | 335.74 | 249.25 |
| | **FOS** | **1.467** | **1.370** | **1.274** | **1.179** | **1.084** | **0.989** | **0.896** | **0.803** | **0.712** | **0.622** | **0.534** | **0.449** | **0.366** | **0.287** | **0.213** |

FAILURE MODE 1: FRONT SLOPE - PHI' = 13°

**c' =** 0
**fo =** 1.054

**Chama & 'F' Plain:** **Phi' =** 14
**tan phi' =** 0.249328

**Numerator =** (c'b + W (1-ru) tan phi ) {(1+ tan$^2$ a)/(1+ tan a tan phi / F)}
**Denominator =** W TAN a

| | | a | b | c | d | e | f | g | h | i | j | k | l | m | n | o |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ru =** | | **0.1** | **0.15** | **0.2** | **0.25** | **0.3** | **0.35** | **0.4** | **0.45** | **0.5** | **0.55** | **0.6** | **0.65** | **0.7** | **0.75** | **0.8** |
| **F =** | | **1.528** | **1.428** | **1.328** | **1.229** | **1.130** | **1.032** | **0.935** | **0.84** | **0.745** | **0.652** | **0.561** | **0.471** | **0.385** | **0.303** | **0.226** |
| **SLICE No.** | **Denom.** | **Numerator** | | | | | | | | | | | | | | |
| 1 | 498.89 | 278.31 | 256.06 | 234.05 | 212.37 | 191.00 | 170.07 | 149.63 | 129.83 | 110.62 | 92.25 | 74.86 | 58.52 | 43.68 | 30.55 | 19.45 |
| 2 | 337.06 | 243.73 | 224.10 | 204.69 | 185.59 | 166.78 | 148.36 | 130.40 | 113.03 | 96.19 | 80.11 | 64.91 | 50.67 | 37.76 | 26.36 | 16.74 |
| 3 | 222.38 | 301.63 | 282.37 | 263.10 | 243.85 | 224.58 | 205.35 | 186.14 | 167.01 | 147.89 | 128.88 | 110.03 | 91.34 | 73.07 | 55.41 | 38.75 |
| 4 | -19.20 | 260.55 | 246.12 | 231.70 | 217.27 | 202.85 | 188.42 | 174.00 | 159.58 | 145.17 | 130.75 | 116.34 | 101.95 | 87.56 | 73.18 | 58.82 |
| 5 | -15.99 | 216.99 | 204.98 | 192.96 | 180.95 | 168.93 | 156.92 | 144.91 | 132.90 | 120.90 | 108.89 | 96.89 | 84.90 | 72.92 | 60.94 | 48.99 |
| 6 | -12.04 | 163.38 | 154.33 | 145.28 | 136.24 | 127.19 | 118.15 | 109.10 | 100.06 | 91.02 | 81.99 | 72.95 | 63.92 | 54.90 | 45.89 | 36.88 |
| 7 | 86.13 | 89.09 | 83.16 | 77.22 | 71.31 | 65.40 | 59.51 | 53.64 | 47.82 | 42.03 | 36.30 | 30.66 | 25.12 | 19.77 | 14.70 | 10.03 |
| 8 | 99.75 | 96.44 | 89.92 | 83.42 | 76.93 | 70.46 | 64.01 | 57.60 | 51.24 | 44.92 | 38.69 | 32.57 | 26.57 | 20.82 | 15.39 | 10.42 |
| 9 | 35.24 | 118.57 | 111.56 | 104.55 | 97.54 | 90.51 | 83.49 | 76.45 | 69.42 | 62.37 | 55.31 | 48.25 | 41.17 | 34.11 | 27.08 | 20.14 |
| 10 | -0.03 | 17.67 | 16.69 | 15.71 | 14.73 | 13.75 | 12.77 | 11.78 | 10.80 | 9.82 | 8.84 | 7.86 | 6.88 | 5.90 | 4.92 | 3.93 |
| **Totals:** | 1232.21 | 1786.36 | 1669.30 | 1552.68 | 1436.77 | 1321.45 | 1207.04 | 1093.65 | 981.70 | 870.91 | 762.01 | 655.34 | 551.04 | 450.48 | 354.42 | 264.16 |
| **FOS** | | **1.528** | **1.428** | **1.328** | **1.229** | **1.130** | **1.032** | **0.935** | **0.840** | **0.745** | **0.652** | **0.561** | **0.471** | **0.385** | **0.303** | **0.226** |

FAILURE MODE 1: FRONT SLOPE - PHI' = 14°

c' = 0
fo = 1.054

**Chama & 'F' Plain:** **Phi' =** 18
**tan phi' =** 0.32492

**Numerator** = (c'b + W (1-ru) tan phi ) {(1+ tan$^2$ a)/(1+ tan a tan phi / F)}
**Denominator** = W TAN a

| | a | b | c | d | e | f | g | h | i | j | k | l | m | n | o |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ru = | **0.1** | **0.15** | **0.2** | **0.25** | **0.3** | **0.35** | **0.4** | **0.45** | **0.5** | **0.55** | **0.6** | **0.65** | **0.7** | **0.75** | **0.8** |
| F = | **1.774** | **1.659** | **1.545** | **1.431** | **1.318** | **1.206** | **1.095** | **0.985** | **0.876** | **0.769** | **0.664** | **0.562** | **0.462** | **0.367** | **0.277** |

| **SLICE No.** | **Denom.** | **Numerator** | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 498.89 | 346.63 | 318.41 | 290.62 | 263.24 | 236.39 | 210.15 | 184.61 | 159.84 | 135.97 | 113.23 | 91.77 | 71.87 | 53.67 | 37.66 | 24.11 |
| 2 | 337.06 | 257.58 | 237.46 | 217.57 | 197.90 | 178.53 | 159.50 | 140.87 | 122.70 | 105.07 | 88.12 | 71.99 | 56.86 | 42.87 | 30.40 | 19.68 |
| 3 | 222.38 | 307.03 | 287.76 | 268.49 | 249.22 | 229.96 | 210.72 | 191.50 | 172.30 | 153.14 | 134.06 | 115.09 | 96.33 | 77.80 | 59.82 | 42.64 |
| 4 | -19.20 | 339.66 | 320.86 | 302.06 | 283.26 | 264.46 | 245.66 | 226.87 | 208.08 | 189.29 | 170.51 | 151.73 | 132.96 | 114.21 | 95.46 | 76.74 |
| 5 | -15.99 | 282.87 | 267.22 | 251.56 | 235.90 | 220.25 | 204.59 | 188.94 | 173.29 | 157.65 | 142.00 | 126.37 | 110.73 | 95.11 | 79.50 | 63.91 |
| 6 | -12.04 | 212.98 | 201.19 | 189.40 | 177.61 | 165.82 | 154.04 | 142.25 | 130.47 | 118.69 | 106.91 | 95.14 | 83.37 | 71.61 | 59.86 | 48.12 |
| 7 | 86.13 | 91.23 | 85.28 | 79.34 | 73.40 | 67.47 | 61.56 | 55.67 | 49.80 | 43.96 | 38.18 | 32.46 | 26.85 | 21.36 | 16.12 | 11.23 |
| 8 | 99.75 | 98.95 | 92.42 | 85.89 | 79.38 | 72.88 | 66.40 | 59.95 | 53.53 | 47.15 | 40.83 | 34.61 | 28.52 | 22.59 | 16.96 | 11.73 |
| 9 | 35.24 | 119.45 | 112.45 | 105.45 | 98.45 | 91.44 | 84.43 | 77.41 | 70.38 | 63.35 | 56.31 | 49.27 | 42.23 | 35.18 | 28.17 | 21.22 |
| 10 | -0.03 | 17.67 | 16.69 | 15.71 | 14.73 | 13.75 | 12.76 | 11.78 | 10.80 | 9.82 | 8.84 | 7.86 | 6.88 | 5.90 | 4.91 | 3.93 |
| **Totals:** | 1232.21 | 2074.05 | 1939.72 | 1806.10 | 1673.08 | 1540.95 | 1409.83 | 1279.85 | 1151.20 | 1024.09 | 899.00 | 776.28 | 656.60 | 540.31 | 428.87 | 323.32 |
| **FOS** | | **1.774** | **1.659** | **1.545** | **1.431** | **1.318** | **1.206** | **1.095** | **0.985** | **0.876** | **0.769** | **0.664** | **0.562** | **0.462** | **0.367** | **0.277** |

FAILURE MODE 1: FRONT SLOPE - PHI' = 18°

**c' =** 0
**fo =** 1.054

**Chama & 'F' Plain:** **Phi' =** 24
**tan phi' =** 0.445229

**Numerator =** (c'b + W (1-ru) tan phi ) {(1+ $\tan^2$ a)/(1+ tan a tan phi / F)}
**Denominator =** W TAN a

| | a | b | c | d | e | f | g | h | i | j | k | l | m | n | o |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ru =** | **0.1** | **0.15** | **0.2** | **0.25** | **0.3** | **0.35** | **0.4** | **0.45** | **0.5** | **0.55** | **0.6** | **0.65** | **0.7** | **0.75** | **0.8** |
| **F =** | **2.154** | **2.016** | **1.879** | **1.742** | **1.607** | **1.473** | **1.339** | **1.207** | **1.077** | **0.948** | **0.822** | **0.699** | **0.579** | **0.464** | **0.354** |

| **SLICE No.** | **Denom.** | **Numerator** | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 498.89 | 451.41 | 413.99 | 377.21 | 341.05 | 305.77 | 271.38 | 237.89 | 205.61 | 174.70 | 145.24 | 117.62 | 92.08 | 68.88 | 48.49 | 31.21 |
| 2 | 337.06 | 274.70 | 254.04 | 233.57 | 213.27 | 193.25 | 173.51 | 154.05 | 135.01 | 116.48 | 98.49 | 81.25 | 64.92 | 49.66 | 35.83 | 23.69 |
| 3 | 222.38 | 313.16 | 293.89 | 274.62 | 255.34 | 236.07 | 216.82 | 197.56 | 178.32 | 159.13 | 139.97 | 120.91 | 101.98 | 83.26 | 64.93 | 47.20 |
| 4 | -19.20 | 465.61 | 439.84 | 414.08 | 388.32 | 362.56 | 336.81 | 311.06 | 285.31 | 259.56 | 233.83 | 208.10 | 182.38 | 156.67 | 130.98 | 105.31 |
| 5 | -15.99 | 387.77 | 366.31 | 344.86 | 323.40 | 301.95 | 280.50 | 259.05 | 237.61 | 216.17 | 194.74 | 173.31 | 151.89 | 130.48 | 109.08 | 87.70 |
| 6 | -12.04 | 291.95 | 275.80 | 259.64 | 243.49 | 227.34 | 211.19 | 195.04 | 178.90 | 162.76 | 146.62 | 130.48 | 114.36 | 98.24 | 82.13 | 66.03 |
| 7 | 86.13 | 93.69 | 87.73 | 81.77 | 75.82 | 69.87 | 63.94 | 58.01 | 52.10 | 46.22 | 40.37 | 34.58 | 28.86 | 23.25 | 17.83 | 12.69 |
| 8 | 99.75 | 101.86 | 95.31 | 88.76 | 82.21 | 75.69 | 69.17 | 62.67 | 56.19 | 49.76 | 43.36 | 37.03 | 30.81 | 24.72 | 18.86 | 13.33 |
| 9 | 35.24 | 120.44 | 113.45 | 106.46 | 99.46 | 92.46 | 85.46 | 78.45 | 71.44 | 64.43 | 57.41 | 50.38 | 43.36 | 36.34 | 29.34 | 22.38 |
| 10 | -0.03 | 17.67 | 16.69 | 15.71 | 14.73 | 13.75 | 12.76 | 11.78 | 10.80 | 9.82 | 8.84 | 7.86 | 6.88 | 5.89 | 4.91 | 3.93 |
| **Totals:** | 1232.21 | 2518.27 | 2357.05 | 2196.68 | 2037.09 | 1878.72 | 1721.55 | 1565.56 | 1411.31 | 1259.04 | 1108.85 | 961.52 | 817.50 | 677.39 | 542.37 | 413.47 |
| **FOS** | | **2.154** | **2.016** | **1.879** | **1.742** | **1.607** | **1.473** | **1.339** | **1.207** | **1.077** | **0.948** | **0.822** | **0.699** | **0.579** | **0.464** | **0.354** |

FAILURE MODE 1: FRONT SLOPE - PHI' = 24°

| Soil Type | Bulk Unit Weight of Soil Strata | |
|---|---|---|
| 1 | 20.00 | $KN/m^3$ |
| 2 | 20.00 | $KN/m^3$ |
| 3 | 20.00 | $KN/m^3$ |

**Drained cohesion of cohesive soil =** **0** $KN/m^2$

**Slipped mass =** **7863.8** $KN/m$

| Slice No. | Width of Slice 'b' | Alpha 'a' | Soil Type 1 | | | Soil Type 2 | | | Soil Type 3 | | | Total Soil Weight 'W' | tan a | Slice Phi' | tan Phi' |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ht. of Slice 1 | | wt. 1 | Ht. of Slice 2 | | wt. 2 | Ht. of Slice 3 | | wt. 3 | | | | |
| | (m) | (Degrees) | LH | RH | (KN/m) | LH | RH | (KN/m) | LH | RH | (KN/m) | (KN/m) | | (Degrees) | |
| 1 | 4.90 | 72.00 | 0.00 | 2.80 | 137.20 | | | 0 | 0 | 7.09 | 347.41 | 484.61 | 3.078 | 40 | 0.839 |
| 2 | 4.40 | 30.60 | 2.80 | 2.80 | 246.40 | | | 0 | 7.09 | 6.70 | 606.76 | 853.16 | 0.591 | 30 | 0.577 |
| 3 | 4.92 | 1.90 | 2.80 | 2.80 | 275.52 | | | 0 | 6.70 | 4.96 | 573.67 | 849.19 | 0.033 | 30 | 0.577 |
| 4 | 8.48 | -0.95 | 2.80 | 2.80 | 474.88 | | | 0 | 4.96 | 3.87 | 748.78 | 1223.66 | -0.017 | | ####### |
| 5 | 1.78 | -0.95 | 2.80 | 2.00 | 85.44 | | | 0 | 3.87 | 4.11 | 142.04 | 227.48 | -0.017 | | ####### |
| 6 | 1.42 | 59.20 | 2.00 | 2.00 | 56.80 | 4.11 | 6.04 | 144.13 | | | 0 | 200.93 | 1.678 | 30 | 0.577 |
| 7 | 3.43 | 21.00 | 2.00 | 2.00 | 137.20 | 6.04 | 6.85 | 442.13 | | | 0 | 579.33 | 0.384 | 30 | 0.577 |
| 8 | 6.77 | -0.95 | 2.00 | 2.00 | 270.80 | 6.85 | 6.25 | 886.87 | | | 0 | 1157.67 | -0.017 | | ####### |
| 9 | 6.70 | -0.95 | 2.00 | 2.00 | 268.00 | 6.25 | 4.14 | 696.13 | | | 0 | 964.13 | -0.017 | | ####### |
| 10 | 8.50 | -0.95 | 2.00 | 2.40 | 374.00 | 4.14 | 0 | 351.90 | | | 0 | 725.90 | -0.017 | | ####### |
| 11 | 3.10 | 28.30 | 2.40 | 2.76 | 159.96 | | | 0 | | | 0 | 159.96 | 0.538 | 30 | 0.577 |
| 12 | 2.80 | 30.70 | 2.76 | 3.24 | 168.00 | | | 0 | | | 0 | 168.00 | 0.594 | 30 | 0.577 |
| 13 | 4.50 | 8.50 | 3.24 | 2.00 | 235.80 | | | 0 | | | 0 | 235.80 | 0.149 | 30 | 0.577 |
| 14 | 1.70 | -0.05 | 2.00 | 0 | 34.00 | | | 0 | | | 0 | 34.00 | -0.001 | 30 | 0.577 |

## Phi' changed for slip surfaces - Chama Bed & 'F' plain

| ru = | 0.25 | 0.3 | 0.35 | 0.4 | 0.45 | 0.5 | 0.55 | 0.6 | 0.65 | 0.7 | 0.75 | 0.8 | 0.85 | 0.9 | 0.95 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Phi' = 12** | 1.196 | 1.083 | 0.974 | 0.867 | 0.764 | 0.665 | 0.570 | 0.480 | 0.395 | 0.315 | 0.242 | 0.176 | 0.118 | 0.07 | 0.03 |
| **Phi' = 13** | 1.228 | 1.113 | 1.002 | 0.894 | 0.789 | 0.687 | 0.590 | 0.497 | 0.411 | 0.329 | 0.253 | 0.186 | 0.125 | 0.074 | 0.032 |
| **Phi' = 14** | 1.261 | 1.144 | 1.030 | 0.920 | 0.813 | 0.709 | 0.610 | 0.515 | 0.426 | 0.342 | 0.265 | 0.194 | 0.131 | 0.078 | 0.034 |
| **Phi' = 18** | 1.390 | 1.265 | 1.144 | 1.024 | 0.909 | 0.797 | 0.690 | 0.586 | 0.488 | 0.395 | 0.308 | 0.229 | 0.157 | 0.095 | 0.043 |
| **Phi' = 24** | 1.587 | 1.451 | 1.317 | 1.186 | 1.057 | 0.932 | 0.811 | 0.695 | 0.583 | 0.476 | 0.376 | 0.283 | 0.197 | 0.121 | 0.057 |

FAILURE MODE 2: ENTIRE SLOPE

c' = 0
fo = 1.043

Chama & 'F' Plain: Phi' = 12
tan phi' = 0.212557

Numerator = (c'b + W (1-ru) tan phi ) {(1+ tan² a)/(1+ tan a tan phi / F)}
Denominator = W TAN a

| | a | b | c | d | e | f | g | h | i | j | k | l | m | n | o |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ru = | 0.25 | 0.3 | 0.35 | 0.4 | 0:45 | 0.5 | 0.55 | 0.6 | 0.65 | 0.7 | 0.75 | 0.8 | 0.85 | 0.9 | 0.95 |
| F = | 1.196 | 1.083 | 0.974 | 0.867 | 0.764 | 0.665 | 0.570 | 0.48 | 0.395 | 0.315 | 0.242 | 0.176 | 0.118 | 0.070 | 0.030 |

| SLICE No. | Denom. | Numerator | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1491.48 | 1010.92 | 880.72 | 758.04 | 642.18 | 534.70 | 436.00 | 346.48 | 266.97 | 197.63 | 138.88 | 91.21 | 54.34 | 27.91 | 11.24 | 2.45 |
| 2 | 504.56 | 387.90 | 353.84 | 319.98 | 286.20 | 252.72 | 219.65 | 187.10 | 155.40 | 124.78 | 95.71 | 68.94 | 45.23 | 25.61 | 11.31 | 2.68 |
| 3 | 28.17 | 362.31 | 337.60 | 312.88 | 288.13 | 263.35 | 238.54 | 213.69 | 188.80 | 163.84 | 138.81 | 113.71 | 88.53 | 63.34 | 38.54 | 14.98 |
| 4 | -20.29 | 195.70 | 182.71 | 169.72 | 156.74 | 143.76 | 130.78 | 117.80 | 104.84 | 91.88 | 78.93 | 66.00 | 53.10 | 40.23 | 27.40 | 14.74 |
| 5 | -3.77 | 36.38 | 33.97 | 31.55 | 29.14 | 26.72 | 24.31 | 21.90 | 19.49 | 17.08 | 14.67 | 12.27 | 9.87 | 7.48 | 5.09 | 2.74 |
| 6 | 337.06 | 183.36 | 163.50 | 144.20 | 125.40 | 107.31 | 90.06 | 73.77 | 58.65 | 44.85 | 32.58 | 22.11 | 13.61 | 7.21 | 2.98 | 0.66 |
| 7 | 222.38 | 242.82 | 223.00 | 203.21 | 183.38 | 163.61 | 143.92 | 124.34 | 105.02 | 86.02 | 67.58 | 50.08 | 33.97 | 20.00 | 9.21 | 2.29 |
| 8 | -19.20 | 185.15 | 172.86 | 160.57 | 148.29 | 136.00 | 123.72 | 111.45 | 99.18 | 86.92 | 74.68 | 62.44 | 50.23 | 38.06 | 25.92 | 13.95 |
| 9 | -15.99 | 154.20 | 143.96 | 133.73 | 123.50 | 113.27 | 103.04 | 92.82 | 82.60 | 72.39 | 62.19 | 52.00 | 41.84 | 31.70 | 21.59 | 11.61 |
| 10 | -12.04 | 116.10 | 108.39 | 100.68 | 92.98 | 85.28 | 77.58 | 69.88 | 62.19 | 54.50 | 46.83 | 39.15 | 31.50 | 23.86 | 16.25 | 8.74 |
| 11 | 86.13 | 70.91 | 64.79 | 58.70 | 52.61 | 46.57 | 40.59 | 34.69 | 28.92 | 23.33 | 17.99 | 13.04 | 8.61 | 4.92 | 2.19 | 0.52 |
| 12 | 99.75 | 76.47 | 69.75 | 63.07 | 56.41 | 49.81 | 43.28 | 36.86 | 30.61 | 24.58 | 18.85 | 13.57 | 8.90 | 5.04 | 2.22 | 0.53 |
| 13 | 35.24 | 97.36 | 90.24 | 83.10 | 75.95 | 68.78 | 61.60 | 54.40 | 47.19 | 39.98 | 32.78 | 25.65 | 18.68 | 12.06 | 6.23 | 1.80 |
| 14 | -0.03 | 14.73 | 13.75 | 12.77 | 11.78 | 10.80 | 9.82 | 8.84 | 7.86 | 6.88 | 5.90 | 4.92 | 3.94 | 2.96 | 1.98 | 1.00 |
| **Totals:** | 2733.46 | 3134.32 | 2839.08 | 2552.21 | 2272.68 | 2002.68 | 1742.89 | 1494.03 | 1257.72 | 1034.66 | 826.37 | 635.10 | 462.34 | 310.37 | 182.15 | 78.69 |
| **FOS** | | **1.196** | **1.083** | **0.974** | **0.867** | **0.764** | **0.665** | **0.570** | **0.480** | **0.395** | **0.315** | **0.242** | **0.176** | **0.118** | **0.070** | **0.030** |

FAILURE MODE 2: ENTIRE SLOPE - PHI' = 12°

c' = 0
fo = 1.043

**Chama & 'F' Plain:** **Phi' =** 13
**tan phi' =** 0.230868

**Numerator =** (c'b + W (1-ru) tan phi ) {(1+ $\tan^2$ a)/(1+ tan a tan phi / F)}
**Denominator =** W TAN a

|  |  | a | b | c | d | e | f | g | h | i | j | k | l | m | n | o |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | **ru =** | **0.25** | **0.3** | **0.35** | **0.4** | **0.45** | **0.5** | **0.55** | **0.6** | **0.65** | **0.7** | **0.75** | **0.8** | **0.85** | **0.9** | **0.95** |
|  | **F =** | **1.228** | **1.113** | **1.002** | **0.894** | **0.789** | **0.687** | **0.590** | **0.497** | **0.411** | **0.329** | **0.253** | **0.186** | **0.125** | **0.074** | **0.032** |
| **SLICE No.** | **Denom.** | **Numerator** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1 | 1491.48 | 1029.25 | 897.77 | 773.74 | 657.04 | 548.10 | 447.39 | 356.37 | 274.90 | 204.63 | 144.36 | 94.99 | 57.22 | 29.49 | 11.86 | 2.61 |
| 2 | 504.56 | 390.16 | 356.14 | 322.32 | 288.66 | 255.22 | 222.06 | 189.51 | 157.64 | 127.10 | 97.88 | 70.74 | 46.89 | 26.73 | 11.84 | 2.85 |
| 3 | 28.17 | 362.46 | 337.76 | 313.05 | 288.32 | 263.55 | 238.75 | 213.92 | 189.04 | 164.14 | 139.15 | 114.07 | 89.00 | 63.84 | 38.99 | 15.35 |
| 4 | -20.29 | 212.60 | 198.49 | 184.38 | 170.28 | 156.18 | 142.08 | 127.99 | 113.91 | 99.83 | 85.77 | 71.73 | 57.70 | 43.73 | 29.80 | 16.05 |
| 5 | -3.77 | 39.52 | 36.90 | 34.28 | 31.66 | 29.03 | 26.41 | 23.79 | 21.18 | 18.56 | 15.95 | 13.34 | 10.73 | 8.13 | 5.54 | 2.98 |
| 6 | 337.06 | 185.52 | 165.61 | 146.24 | 127.43 | 109.25 | 91.80 | 75.37 | 60.02 | 46.14 | 33.66 | 22.91 | 14.26 | 7.59 | 3.14 | 0.71 |
| 7 | 222.38 | 243.82 | 224.02 | 204.26 | 184.51 | 164.78 | 145.08 | 125.54 | 106.16 | 87.26 | 68.79 | 51.14 | 35.02 | 20.76 | 9.61 | 2.42 |
| 8 | -19.20 | 201.13 | 187.79 | 174.44 | 161.10 | 147.76 | 134.42 | 121.09 | 107.77 | 94.45 | 81.15 | 67.86 | 54.59 | 41.37 | 28.19 | 15.18 |
| 9 | -15.99 | 167.51 | 156.39 | 145.28 | 134.16 | 123.05 | 111.95 | 100.85 | 89.75 | 78.66 | 67.58 | 56.52 | 45.47 | 34.45 | 23.48 | 12.65 |
| 10 | -12.04 | 126.12 | 117.75 | 109.38 | 101.01 | 92.65 | 84.29 | 75.93 | 67.57 | 59.22 | 50.88 | 42.55 | 34.23 | 25.94 | 17.68 | 9.52 |
| 11 | 86.13 | 71.30 | 65.18 | 59.10 | 53.03 | 47.00 | 41.01 | 35.11 | 29.31 | 23.74 | 18.38 | 13.36 | 8.92 | 5.12 | 2.29 | 0.56 |
| 12 | 99.75 | 76.92 | 70.21 | 63.54 | 56.90 | 50.30 | 43.76 | 37.34 | 31.06 | 25.04 | 19.27 | 13.93 | 9.23 | 5.26 | 2.33 | 0.56 |
| 13 | 35.24 | 97.53 | 90.42 | 83.29 | 76.16 | 69.00 | 61.82 | 54.64 | 47.44 | 40.26 | 33.08 | 25.95 | 19.01 | 12.35 | 6.43 | 1.88 |
| 14 | -0.03 | 14.73 | 13.75 | 12.77 | 11.78 | 10.80 | 9.82 | 8.84 | 7.86 | 6.88 | 5.90 | 4.92 | 3.94 | 2.96 | 1.98 | 1.00 |
| **Totals:** | 2733.46 | 3218.57 | 2918.17 | 2626.07 | 2342.04 | 2066.68 | 1800.66 | 1546.30 | 1303.62 | 1075.91 | 861.78 | 664.00 | 486.21 | 327.71 | 193.15 | 84.31 |
|  | **FOS** | **1.228** | **1.113** | **1.002** | **0.894** | **0.789** | **0.687** | **0.590** | **0.497** | **0.411** | **0.329** | **0.253** | **0.186** | **0.125** | **0.074** | **0.032** |

FAILURE MODE 2: ENTIRE SLOPE - PHI' = 13°

c' = 0
fo = 1.043

Chama & 'F' Plain: Phi' = 14
tan phi' = 0.249328

**Numerator** = (c'b + W (1-ru) tan phi ) {(1+ tan$^2$ a)/(1+ tan a tan phi / F)}
**Denominator** = W TAN a

| | a | b | c | d | e | f | g | h | i | j | k | l | m | n | o |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ru =** | **0.25** | **0.3** | **0.35** | **0.4** | **0.45** | **0.5** | **0.55** | **0.6** | **0.65** | **0.7** | **0.75** | **0.8** | **0.85** | **0.9** | **0.95** |
| **F =** | **1.261** | **1.144** | **1.030** | **0.92** | **0.813** | **0.709** | **0.610** | **0.515** | **0.426** | **0.342** | **0.265** | **0.194** | **0.131** | **0.078** | **0.034** |

| **SLICE No.** | **Denom.** | **Numerator** | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1491.48 | 1047.83 | 915.09 | 789.20 | 671.13 | 560.78 | 458.63 | 366.15 | 283.20 | 211.04 | 149.40 | 99.08 | 59.51 | 30.84 | 12.48 | 2.77 |
| 2 | 504.56 | 392.39 | 358.42 | 324.56 | 290.93 | 257.52 | 224.37 | 191.82 | 159.92 | 129.17 | 99.81 | 72.63 | 48.18 | 27.65 | 12.36 | 3.01 |
| 3 | 28.17 | 362.61 | 337.92 | 313.21 | 288.49 | 263.74 | 238.96 | 214.15 | 189.29 | 164.40 | 139.44 | 114.43 | 89.34 | 64.23 | 39.41 | 15.70 |
| 4 | -20.29 | 229.64 | 214.40 | 199.16 | 183.93 | 168.71 | 153.48 | 138.27 | 123.06 | 107.86 | 92.67 | 77.50 | 62.36 | 47.27 | 32.23 | 17.37 |
| 5 | -3.77 | 42.69 | 39.86 | 37.03 | 34.19 | 31.36 | 28.53 | 25.70 | 22.88 | 20.05 | 17.23 | 14.41 | 11.59 | 8.79 | 5.99 | 3.23 |
| 6 | 337.06 | 187.69 | 167.72 | 148.22 | 129.33 | 111.05 | 93.50 | 76.94 | 61.44 | 47.31 | 34.64 | 23.76 | 14.77 | 7.91 | 3.30 | 0.75 |
| 7 | 222.38 | 244.80 | 225.04 | 205.28 | 185.56 | 165.86 | 146.18 | 126.67 | 107.32 | 88.35 | 69.86 | 52.25 | 35.83 | 21.39 | 9.99 | 2.55 |
| 8 | -19.20 | 217.25 | 202.84 | 188.42 | 174.01 | 159.61 | 145.21 | 130.81 | 116.42 | 102.04 | 87.68 | 73.32 | 59.00 | 44.72 | 30.49 | 16.43 |
| 9 | -15.99 | 180.93 | 168.93 | 156.92 | 144.92 | 132.92 | 120.93 | 108.94 | 96.96 | 84.98 | 73.02 | 61.07 | 49.14 | 37.24 | 25.39 | 13.69 |
| 10 | -12.04 | 136.22 | 127.19 | 118.15 | 109.11 | 100.08 | 91.05 | 82.02 | 73.00 | 63.98 | 54.98 | 45.98 | 37.00 | 28.04 | 19.12 | 10.30 |
| 11 | 86.13 | 71.68 | 65.57 | 59.48 | 53.42 | 47.40 | 41.41 | 35.51 | 29.71 | 24.10 | 18.72 | 13.70 | 9.16 | 5.30 | 2.39 | 0.59 |
| 12 | 99.75 | 77.36 | 70.66 | 63.98 | 57.35 | 50.75 | 44.22 | 37.80 | 31.50 | 25.44 | 19.66 | 14.30 | 9.48 | 5.44 | 2.43 | 0.59 |
| 13 | 35.24 | 97.70 | 90.59 | 83.47 | 76.35 | 69.20 | 62.04 | 54.87 | 47.68 | 40.51 | 33.34 | 26.25 | 19.27 | 12.59 | 6.61 | 1.97 |
| 14 | -0.03 | 14.73 | 13.75 | 12.77 | 11.78 | 10.80 | 9.82 | 8.84 | 7.86 | 6.88 | 5.90 | 4.92 | 3.94 | 2.96 | 1.98 | 1.00 |
| **Totals:** | 2733.46 | 3303.52 | 2997.97 | 2699.85 | 2410.51 | 2129.78 | 1858.34 | 1598.48 | 1350.25 | 1116.12 | 896.33 | 693.60 | 508.56 | 344.35 | 204.16 | 89.95 |
| | **FOS** | **1.261** | **1.144** | **1.030** | **0.920** | **0.813** | **0.709** | **0.610** | **0.515** | **0.426** | **0.342** | **0.265** | **0.194** | **0.131** | **0.078** | **0.034** |

FAILURE MODE 2: ENTIRE SLOPE - PHI' = 14°

**c' =** 0
**fo =** 1.043

**Chama & 'F' Plain:** **Phi' =** 18
**tan phi' =** 0.32492

**Numerator =** (c'b + W (1-ru) tan phi ) {(1+ tan² a)/(1+ tan a tan phi / F)}
**Denominator =** W TAN a

|  |  | a | b | c | d | e | f | g | h | i | j | k | l | m | n | o |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ru =** |  | **0.25** | **0.3** | **0.35** | **0.4** | **0.45** | **0.5** | **0.55** | **0.6** | **0.65** | **0.7** | **0.75** | **0.8** | **0.85** | **0.9** | **0.95** |
| **F =** |  | **1.39** | **1.265** | **1.144** | **1.024** | **0.909** | **0.797** | **0.690** | **0.586** | **0.488** | **0.395** | **0.308** | **0.229** | **0.157** | **0.095** | **0.043** |
| **SLICE No.** | **Denom.** | **Numerator** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1 | 1491.48 | 1117.52 | 980.06 | 849.73 | 725.45 | 609.76 | 502.13 | 404.04 | 315.03 | 236.88 | 169.48 | 113.44 | 69.37 | 36.61 | 15.11 | 3.49 |
| 2 | 504.56 | 400.31 | 366.48 | 332.82 | 299.16 | 265.82 | 232.72 | 200.14 | 168.03 | 136.91 | 106.98 | 78.83 | 53.38 | 31.41 | 14.47 | 3.72 |
| 3 | 28.17 | 363.11 | 338.45 | 313.78 | 289.09 | 264.38 | 239.65 | 214.90 | 190.11 | 165.30 | 140.44 | 115.52 | 90.59 | 65.62 | 40.85 | 16.98 |
| 4 | -20.29 | 299.44 | 279.58 | 259.73 | 239.88 | 220.04 | 200.20 | 180.37 | 160.56 | 140.75 | 120.96 | 101.20 | 81.46 | 61.78 | 42.16 | 22.73 |
| 5 | -3.77 | 55.67 | 51.98 | 48.28 | 44.60 | 40.91 | 37.22 | 33.53 | 29.85 | 26.17 | 22.49 | 18.81 | 15.14 | 11.48 | 7.84 | 4.23 |
| 6 | 337.06 | 195.57 | 175.42 | 155.74 | 136.43 | 117.82 | 99.87 | 82.84 | 66.72 | 51.89 | 38.45 | 26.69 | 16.92 | 9.26 | 3.95 | 0.94 |
| 7 | 222.38 | 248.24 | 228.58 | 208.96 | 189.29 | 169.69 | 150.13 | 130.71 | 111.38 | 92.37 | 73.75 | 55.79 | 39.00 | 23.87 | 11.51 | 3.12 |
| 8 | -19.20 | 283.29 | 264.50 | 245.72 | 226.95 | 208.17 | 189.41 | 170.65 | 151.90 | 133.16 | 114.44 | 95.74 | 77.06 | 58.44 | 39.89 | 21.51 |
| 9 | -15.99 | 235.93 | 220.28 | 204.64 | 189.01 | 173.37 | 157.74 | 142.12 | 126.50 | 110.90 | 95.31 | 79.73 | 64.18 | 48.67 | 33.22 | 17.91 |
| 10 | -12.04 | 177.63 | 165.85 | 154.08 | 142.30 | 130.53 | 118.76 | 107.00 | 95.25 | 83.50 | 71.76 | 60.03 | 48.32 | 36.65 | 25.01 | 13.49 |
| 11 | 86.13 | 73.02 | 66.94 | 60.89 | 54.83 | 48.82 | 42.85 | 36.96 | 31.13 | 25.47 | 20.00 | 14.82 | 10.11 | 6.00 | 2.79 | 0.72 |
| 12 | 99.75 | 78.93 | 72.25 | 65.61 | 58.97 | 52.40 | 45.87 | 39.44 | 33.11 | 26.97 | 21.07 | 15.52 | 10.51 | 6.18 | 2.85 | 0.73 |
| 13 | 35.24 | 98.28 | 91.20 | 84.12 | 77.02 | 69.91 | 62.79 | 55.67 | 48.53 | 41.39 | 34.27 | 27.18 | 20.22 | 13.47 | 7.29 | 2.31 |
| 14 | -0.03 | 14.73 | 13.75 | 12.77 | 11.78 | 10.80 | 9.82 | 8.84 | 7.86 | 6.88 | 5.90 | 4.92 | 3.93 | 2.95 | 1.97 | 0.99 |
| **Totals:** | 2733.46 | 3641.66 | 3315.33 | 2996.88 | 2684.76 | 2382.43 | 2089.18 | 1807.21 | 1535.95 | 1278.51 | 1035.28 | 808.22 | 600.20 | 412.39 | 248.91 | 112.87 |
|  | **FOS** | **1.390** | **1.265** | **1.144** | **1.024** | **0.909** | **0.797** | **0.690** | **0.586** | **0.488** | **0.395** | **0.308** | **0.229** | **0.157** | **0.095** | **0.043** |

FAILURE MODE 2: ENTIRE SLOPE - PHI' = 18°

c' = 0
fo = 1.043

**Chama & 'F' Plain:** **Phi' =** 24
**tan phi' =** 0.445229

**Numerator =** (c'b + W (1-ru) tan phi ) $\{(1+\tan^2 a)/(1+\tan a \tan \text{phi} / F)\}$
**Denominator =** W TAN a

|  |  | a | b | c | d | e | f | g | h | i | j | k | l | m | n | o |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ru =** |  | **0.25** | **0.3** | **0.35** | **0.4** | **0.45** | **0.5** | **0.55** | **0.6** | **0.65** | **0.7** | **0.75** | **0.8** | **0.85** | **0.9** | **0.95** |
| **F =** |  | **1.587** | **1.451** | **1.317** | **1.186** | **1.057** | **0.932** | **0.811** | **0.695** | **0.583** | **0.476** | **0.376** | **0.283** | **0.197** | **0.121** | **0.057** |
| **SLICE No.** | **Denom.** | **Numerator** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1 | 1491.48 | 1215.62 | 1072.32 | 934.83 | 804.10 | 680.20 | 564.63 | 457.96 | 361.20 | 274.50 | 198.82 | 135.30 | 84.11 | 45.27 | 19.06 | 4.60 |
| 2 | 504.56 | 410.35 | 376.74 | 343.18 | 309.74 | 276.39 | 243.29 | 210.54 | 178.33 | 146.75 | 116.14 | 87.11 | 60.26 | 36.49 | 17.40 | 4.76 |
| 3 | 28.17 | 363.73 | 339.10 | 314.46 | 289.81 | 265.15 | 240.47 | 215.77 | 191.06 | 166.32 | 141.55 | 116.76 | 91.94 | 67.10 | 42.37 | 18.37 |
| 4 | -20.29 | 410.63 | 383.42 | 356.22 | 329.02 | 301.84 | 274.66 | 247.49 | 220.32 | 193.18 | 166.06 | 138.97 | 111.91 | 84.93 | 58.04 | 31.30 |
| 5 | -3.77 | 76.34 | 71.28 | 66.22 | 61.17 | 56.11 | 51.06 | 46.01 | 40.96 | 35.91 | 30.87 | 25.83 | 20.80 | 15.79 | 10.79 | 5.82 |
| 6 | 337.06 | 206.08 | 185.74 | 165.72 | 146.14 | 126.99 | 108.49 | 90.74 | 73.94 | 58.19 | 43.74 | 30.93 | 20.01 | 11.22 | 4.91 | 1.23 |
| 7 | 222.38 | 252.55 | 233.04 | 213.51 | 194.00 | 174.48 | 155.02 | 135.63 | 116.39 | 97.32 | 78.55 | 60.36 | 43.04 | 27.09 | 13.55 | 3.93 |
| 8 | -19.20 | 388.48 | 362.74 | 337.01 | 311.28 | 285.56 | 259.84 | 234.14 | 208.44 | 182.76 | 157.11 | 131.47 | 105.88 | 80.35 | 54.91 | 29.61 |
| 9 | -15.99 | 323.54 | 302.10 | 280.67 | 259.24 | 237.82 | 216.40 | 194.99 | 173.59 | 152.21 | 130.84 | 109.49 | 88.18 | 66.91 | 45.73 | 24.66 |
| 10 | -12.04 | 243.59 | 227.45 | 211.32 | 195.18 | 179.05 | 162.93 | 146.81 | 130.70 | 114.60 | 98.51 | 82.44 | 66.39 | 50.38 | 34.43 | 18.57 |
| 11 | 86.13 | 74.71 | 68.68 | 62.65 | 56.63 | 50.63 | 44.67 | 38.75 | 32.92 | 27.19 | 21.62 | 16.30 | 11.35 | 6.93 | 3.34 | 0.92 |
| 12 | 99.75 | 80.91 | 74.28 | 67.66 | 61.06 | 54.48 | 47.96 | 41.50 | 35.14 | 28.91 | 22.88 | 17.16 | 11.87 | 7.18 | 3.42 | 0.94 |
| 13 | 35.24 | 99.00 | 91.96 | 84.90 | 77.84 | 70.77 | 63.69 | 56.61 | 49.52 | 42.43 | 35.35 | 28.30 | 21.33 | 14.52 | 8.12 | 2.77 |
| 14 | -0.03 | 14.73 | 13.75 | 12.76 | 11.78 | 10.80 | 9.82 | 8.84 | 7.86 | 6.88 | 5.90 | 4.91 | 3.93 | 2.95 | 1.97 | 0.99 |
| **Totals:** | 2733.46 | 4160.26 | 3802.61 | 3451.12 | 3107.01 | 2770.28 | 2442.93 | 2125.78 | 1820.39 | 1527.17 | 1247.95 | 985.35 | 741.01 | 517.11 | 318.04 | 148.46 |
| **FOS** |  | **1.587** | **1.451** | **1.317** | **1.186** | **1.057** | **0.932** | **0.811** | **0.695** | **0.583** | **0.476** | **0.376** | **0.283** | **0.197** | **0.121** | **0.057** |

FAILURE MODE 2:ENTIRE SLOPE - PHI' = 24°

## Average Pore Pressure Ratio Calculation for Cliff at Barton-on-Sea

## Case 1

**Pore Pressure Head height, h, @ grid points (m).**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 0.70 | 0.31 | 0.11 | 0 | | | | | | | | | | | | | | | |
| B | 4.00 | 3.83 | 3.65 | 3.45 | 3.01 | 2.58 | 1.53 | 0 | | | | | | | | | | | |
| C | 7.30 | 7.24 | 7.18 | 7.12 | 7.10 | 6.84 | 5.59 | 4.08 | 2.97 | 1.99 | 0.73 | 0 | | | | | | | |
| D | | | | | | | | 8.28 | 7.63 | 7.21 | 6.90 | 6.62 | 4.01 | 3.01 | 2.58 | 1.51 | 0 | | |
| E | | | | | | | | | | | | | 8.90 | 7.20 | 7.18 | 6.88 | 6.36 | 5.93 | 3.28 |

**Pore Water Pressure, U (kPa), @ grid points.** U = wt of water * h wt of water = 9.81 kN/m³

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 6.9 | 3.0 | 1.1 | 0.0 | | | | | | | | | | | | | | | |
| B | 39.2 | 37.6 | 35.8 | 33.8 | 29.5 | 25.3 | 15.0 | 0.0 | | | | | | | | | | | |
| C | 71.6 | 71.1 | 70.5 | 69.8 | 69.6 | 67.1 | 54.9 | 40.0 | 29.1 | 19.6 | 7.1 | 0.0 | | | | | | | |
| D | | | | | | | | 81.2 | 74.8 | 70.8 | 67.7 | 65.0 | 39.3 | 29.5 | 25.3 | 14.8 | 0.0 | | |
| E | | | | | | | | | | | | | 87.3 | 70.6 | 70.4 | 67.5 | 62.4 | 58.2 | 32.2 |

**G.L. height, ha, for Pore Pressure Ratio, ru, @ grid points.**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 9.8 | 9.8 | 9.7 | 0.0 | | | | | | | | | | | | | | | |
| B | 13.1 | 13.1 | 13.0 | 12.9 | 10.0 | 6.4 | 3.7 | 0.0 | | | | | | | | | | | |
| C | 16.4 | 16.4 | 16.3 | 16.2 | 13.3 | 9.7 | 7.0 | 5.0 | 4.7 | 3.0 | 2.7 | 0.0 | | | | | | | |
| D | | | | | | | | 8.3 | 8.0 | 6.3 | 6.0 | 5.4 | 4.7 | 4.3 | 4.0 | 3.3 | 0.0 | | |
| E | | | | | | | | | | | | | 8.0 | 7.6 | 7.3 | 6.6 | 5.7 | 4.7 | 3.3 |

**Pore Pressure Ratio, ru, @ grid points.** ru = U / (ha * wt of soil ) wt of soil = 20 kN/m³

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 0.04 | 0.02 | 0.01 | | | | | | | | | | | | | | | | |
| B | 0.15 | 0.14 | 0.14 | 0.13 | 0.15 | 0.20 | 0.20 | | | | | | | | | | | | |
| C | 0.22 | 0.22 | 0.22 | 0.22 | 0.26 | 0.35 | 0.39 | 0.40 | 0.31 | 0.33 | 0.13 | | | | | | | | |
| D | | | | | | | | 0.49 | 0.47 | 0.56 | 0.56 | 0.60 | 0.42 | 0.34 | 0.32 | 0.22 | | | |
| E | | | | | | | | | | | | | 0.55 | 0.46 | 0.48 | 0.51 | 0.55 | 0.62 | 0.49 |
| | 0.40 | 0.38 | 0.36 | 0.3 | 0.41 | 0.54 | 0.59 | 0.89 | 0.78 | 0.89 | 0.70 | 0.60 | 0.96 | 0.81 | 0.80 | 0.74 | 0.55 | 0.62 | 0.49 |

**Height, hi, for Pore Pressure Ratio, ru, @ grid points.**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 9.8 | 9.8 | 9.7 | 0.0 | | | | | | | | | | | | | | | |
| B | 3.3 | 3.3 | 3.3 | 12.9 | 10.0 | 6.4 | 3.7 | 0.0 | | | | | | | | | | | |
| C | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 5.0 | 4.7 | 3.0 | 2.7 | 0.0 | | | | | | | |
| D | | | | | | | | 3.3 | 3.3 | 3.3 | 3.3 | 5.4 | 4.7 | 4.3 | 4.0 | 3.3 | 0.0 | | |
| E | | | | | | | | | | | | | 3.3 | 3.3 | 3.3 | 3.3 | 5.7 | 4.7 | 3.3 |
| | 16.4 | 16.4 | 16.3 | 16.2 | 13.3 | 9.7 | 7.0 | 8.3 | 8.0 | 6.3 | 6.0 | 5.4 | 8.0 | 7.6 | 7.3 | 6.6 | 5.7 | 4.7 | 3.3 |

**ru bar for each slice area** ru bar = SUM(hi * ru) / SUM(hi)

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.40 | 0.38 | 0.36 | 0.35 | 0.41 | 0.54 | 0.59 | 0.89 | 0.78 | 0.89 | 0.70 | 0.60 | 0.96 | 0.81 | 0.80 | 0.74 | 0.55 | 0.62 | 0.49 |

**Area of slices** Area = width of slice * average ht of slice width of slices = 3.33 m

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 32.7 | 32.7 | 32.3 | 43 | 33.3 | 21.3 | 12.3 | 16.7 | 15.7 | 10 | 9 | 18 | 15.7 | 14.3 | 13.3 | 11 | 19 | 15.7 | 11 |

**Total slice area = 377 m²**

**ru bar * slice area**

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13.2 | 12.3 | 11.6 | 14.9 | 13.6 | 11.6 | 7.33 | 14.8 | 12.2 | 8.88 | 6.27 | 10.8 | 15.1 | 11.6 | 10.7 | 8.10 | 10.4 | 9.7 | 5.36 |

**Total (ru bar * slice area) = 208**

**Average Pore Pressure Ratio, ru bar**

$$\frac{\textbf{Total (ru bar * slice area )}}{\textbf{Total slice area}} = \boxed{\textbf{0.55}}$$

# Average Pore Pressure Ratio Calculation for Cliff at Barton-on-Sea

## Case 2

**Pore Pressure Head height, h, @ grid points (m).**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 0.70 | 0.61 | 0.41 | | | | | | | | | | | | | | | | |
| B | 4.00 | 3.97 | 3.82 | 3.56 | 3.09 | 1.90 | | | | | | | | | | | | | |
| C | 7.30 | 7.34 | 7.22 | 7.26 | 7.21 | 6.76 | 4.68 | 2.67 | 0.56 | | | | | | | | | | |
| D | | | | | | | | 7.61 | 6.73 | 6.51 | 6.18 | 6.82 | 3.24 | 2.15 | 1.56 | 0.54 | | | |
| E | | | | | | | | | | | | | 8.62 | 6.93 | 6.76 | 6.59 | 6.23 | 5.22 | 2.62 |

**Pore Water Pressure, U (kPa), @ grid points.** U = wt of water * h wt of water = 9.81 kN/m³

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 6.87 | 5.95 | 4.01 | | | | | | | | | | | | | | | | |
| B | 39.24 | 38.99 | 37.43 | 34.92 | 30.32 | 18.61 | | | | | | | | | | | | | |
| C | 71.61 | 72.03 | 70.85 | 71.27 | 70.70 | 66.27 | 45.95 | 26.19 | 5.46 | | | | | | | | | | |
| D | | | | | | | | 74.65 | 66.03 | 63.88 | 60.63 | 66.94 | 31.75 | 21.12 | 15.32 | 5.35 | | | |
| E | | | | | | | | | | | | | 84.61 | 68.02 | 66.32 | 64.68 | 61.12 | 51.18 | 25.68 |

**G.L. height, ha, for Pore Pressure Ratio, ru, @ grid points.**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 9.80 | 9.80 | 9.70 | | | | | | | | | | | | | | | | |
| B | 13.10 | 13.10 | 13.00 | 12.90 | 10.00 | 6.40 | | | | | | | | | | | | | |
| C | 16.40 | 16.40 | 16.30 | 16.20 | 13.30 | 9.70 | 7.00 | 5.00 | 4.70 | | | | | | | | | | |
| D | | | | | | | | 8.30 | 8.00 | 6.30 | 6.00 | 5.40 | 4.70 | 4.30 | 4.00 | 3.30 | | | |
| E | | | | | | | | | | | | | 8.00 | 7.60 | 7.30 | 6.60 | 5.70 | 4.70 | 3.30 |

**Pore Pressure Ratio, ru, @ grid points.** ru = U / (ha * wt of soil ) wt of soil = 20 kN/m³

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 0.04 | 0.03 | 0.02 | | | | | | | | | | | | | | | | |
| B | 0.15 | 0.15 | 0.14 | 0.14 | 0.15 | 0.15 | | | | | | | | | | | | | |
| C | 0.22 | 0.22 | 0.22 | 0.22 | 0.27 | 0.34 | 0.33 | 0.26 | 0.06 | | | | | | | | | | |
| D | | | | | | | | 0.45 | 0.41 | 0.51 | 0.51 | 0.62 | 0.34 | 0.25 | 0.19 | 0.08 | | | |
| E | | | | | | | | | | | | | 0.53 | 0.45 | 0.45 | 0.49 | 0.54 | 0.54 | 0.39 |
| | 0.40 | 0.40 | 0.38 | 0.4 | 0.42 | 0.49 | 0.33 | 0.71 | 0.47 | 0.51 | 0.51 | 0.62 | 0.87 | 0.69 | 0.65 | 0.57 | 0.54 | 0.54 | 0.39 |

**Height, hi, for Pore Pressure Ratio, ru, @ grid points.**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 9.8 | 9.8 | 9.7 | | | | | | | | | | | | | | | | |
| B | 3.3 | 3.3 | 3.3 | 12.9 | 10.0 | 6.4 | 3.7 | | | | | | | | | | | | |
| C | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 5.0 | 4.7 | 3.0 | 2.7 | | | | | | | | |
| D | | | | | | | | 3.3 | 3.3 | 3.3 | 3.3 | 5.4 | 4.7 | 4.3 | 4.0 | 3.3 | | | |
| E | | | | | | | | | | | | | 3.3 | 3.3 | 3.3 | 3.3 | 5.7 | 4.7 | 3.3 |
| | 16.4 | 16.4 | 16.3 | 16.2 | 13.3 | 9.7 | 7.0 | 8.3 | 8.0 | 6.3 | 6.0 | 5.4 | 8.0 | 7.6 | 7.3 | 6.6 | 5.7 | 4.7 | 3.3 |

**ru bar for each slice area** ru bar = SUM(hi * ru) / SUM(hi)

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.40 | 0.40 | 0.38 | 0.36 | 0.42 | 0.49 | 0.33 | 0.71 | 0.47 | 0.51 | 0.51 | 0.62 | 0.87 | 0.69 | 0.65 | 0.57 | 0.54 | 0.54 | 0.39 |

**Area of slices** Area = width of slice * average ht of slice width of slices = 3.33 m

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 32.7 | 32.7 | 32.3 | 43 | 33.3 | 21.3 | 12.3 | 16.7 | 15.7 | 10 | 9 | 18 | 15.7 | 14.3 | 13.3 | 11 | 19 | 15.7 | 11 |

**Total slice area = 377 m²**

**ru bar * slice area**

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13.2 | 13 | 12.3 | 15.3 | 13.9 | 10.4 | 4.05 | 11.9 | 7.37 | 5.07 | 4.55 | 11.2 | 13.6 | 9.93 | 8.61 | 6.28 | 10.2 | 8.53 | 4.28 |

**Total (ru bar * slice area) = 184**

**Average Pore Pressure Ratio, ru bar**

$$\frac{\textbf{Total (ru bar * slice area )}}{\textbf{Total slice area}} = \textbf{0.49}$$

# APPENDIX C

Results of accuracy experiment

NFDC Flow Monitoring Data:

- Manholes - Raw data
- Catchpits - Raw data
- Manholes - Estimate of total flow
- Catchpits - Estimate of total flow and comparison with manholes estimate of total flow
- Mole Drains - Estimate of total flow

## RESULTS OF EXPERIMENT TO TEST THE RELIABILITY OF MONITORING DATA

MANHOLE 13

| | 0930hrs | | | 4th November | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | | | 2 | | | 3 | | |
| | Litres | Seconds | (lt/day) | Litres | Seconds | (lt/day) | Litres | Seconds | (lt/day) |
| PIPE A | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 |
| PIPE B | 0.50 | 34 | 1271 | 0.50 | 44 | 982 | 0.75 | 49 | 1322 |
| PIPE C | 1.75 | 37 | 4086 | 2.00 | 45 | 3840 | 2.25 | 44 | 4418 |
| PIPE D | 2.00 | 36 | 4800 | 2.00 | 34 | 5082 | 2.00 | 33 | 5236 |
| PIPE E | 1.00 | 38 | 2274 | 1.00 | 39 | 2215 | 1.00 | 37 | 2335 |
| PIPE F | 1.00 | 58 | 1490 | 1.00 | 56 | 1543 | 1.00 | 54 | 1600 |
| PIPE G | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 |

| ERRORS | | | | |
|---|---|---|---|---|
| min. | max | DIFFERENCE | | Average |
| (lt / day) | | (%) | (lt/day) | (lt/day) |
| 0 | 0 | N/A | N/A | 0 |
| 982 | 1322 | 35% | 341 | 1192 |
| 3840 | 4418 | 15% | 578 | 4115 |
| 4800 | 5236 | 9% | 436 | 5040 |
| 2215 | 2335 | 5% | 120 | 2275 |
| 1490 | 1600 | 7% | 110 | 1544 |
| 0 | 0 | N/A | N/A | 0 |

| | 1230hrs | | | 4th November | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | | | 2 | | | 3 | | |
| | Litres | Seconds | (lt/day) | Litres | Seconds | (lt/day) | Litres | Seconds | (lt/day) |
| PIPE A | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 |
| PIPE B | 0.50 | 36 | 1200 | 0.50 | 36 | 1200 | 0.75 | 41 | 1580 |
| PIPE C | 2.00 | 40 | 4320 | 2.00 | 40 | 4320 | 2.25 | 41 | 4741 |
| PIPE D | 2.00 | 34 | 5082 | 2.00 | 31 | 5574 | 2.00 | 30 | 5760 |
| PIPE E | 1.00 | 33 | 2618 | 1.25 | 44 | 2455 | 1.50 | 43 | 3014 |
| PIPE F | 1.00 | 49 | 1763 | 1.00 | 53 | 1630 | 1.00 | 43 | 2009 |
| PIPE G | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 |

| ERRORS | | | | |
|---|---|---|---|---|
| min. | max | DIFFERENCE | | Average |
| (lt / day) | | (%) | (lt/day) | (lt/day) |
| 0 | 0 | N/A | N/A | 0 |
| 1200 | 1580 | 32% | 380 | 1327 |
| 4320 | 4741 | 10% | 421 | 4460 |
| 5082 | 5760 | 13% | 678 | 5472 |
| 2455 | 3014 | 23% | 559 | 2696 |
| 1630 | 2009 | 23% | 379 | 1801 |
| 0 | 0 | N/A | N/A | 0 |

ERRORS BETWEEEN DIFFERENT TIMES

| 0930hrs | 1230hrs | | |
|---|---|---|---|
| Average (lt/day) | Average (lt/day) | DIFFERENCE (%) | (lt/day) |
| 0 | 0 | N/A | N/A |
| 1191.6185 | 1326.8293 | 11% | 135 |
| 4114.8894 | 4460.4878 | 8% | 346 |
| 5039.5722 | 5472.1822 | 9% | 433 |
| 2274.7347 | 2695.5603 | 18% | 421 |
| 1544.1708 | 1800.9188 | 17% | 257 |
| 0 | 0 | N/A | N/A |

**Key**

▭ = Largest Difference in range

MANHOLE 17

| | 0845hrs | | 4th November | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | | | 2 | | | 3 | | |
| | Litres | Seconds | (lt/day) | Litres | Seconds | (lt/day) | Litres | Seconds | (lt/day) |
| PIPE A | 1.00 | 4 | 21600 | 1.00 | 7 | 12343 | 1.25 | 6 | 18000 |
| PIPE B | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 |
| PIPE C | 1.00 | 20 | 4320 | 1.00 | 19 | 4547 | 1.00 | 22 | 3927 |
| PIPE D | 1.00 | 24 | 3600 | 1.00 | 24 | 3600 | 1.00 | 24 | 3600 |

| ERRORS | | | | |
|---|---|---|---|---|
| min. | max | DIFFERENCE | | Average |
| (lt / day) | | (%) | (lt/day) | (lt/day) |
| 12343 | 21600 | 75% | 9257 | 17314.286 |
| 0 | 0 | N/A | N/A | 0 |
| 3927 | 4547 | 16% | 620 | 4265 |
| 3600 | 3600 | 0% | 0 | 3600 |

| | 1145hrs | | 4th November | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | | | 2 | | | 3 | | |
| | Litres | Seconds | (lt/day) | Litres | Seconds | (lt/day) | Litres | Seconds | (lt/day) |
| PIPE A | 1.00 | 4 | 21600 | 1.00 | 5 | 17280 | 1.25 | 6 | 18000 |
| PIPE B | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 |
| PIPE C | 1.50 | 32 | 4050 | 1.50 | 30 | 4320 | 1.50 | 30 | 4320 |
| PIPE D | 1.50 | 34 | 3811.7647 | 1.50 | 37 | 3502.7027 | 1.50 | 38 | 3411 |

| ERRORS | | | | |
|---|---|---|---|---|
| min. | max | DIFFERENCE | | Average |
| (lt / day) | | (%) | (lt/day) | (lt/day) |
| 17280 | 21600 | 25% | 4320 | 18960 |
| 0 | 0 | N/A | N/A | 0 |
| 4050 | 4320 | 7% | 270 | 4230 |
| 3411 | 3812 | 12% | 401 | 3575 |

ERRORS BETWEEEN DIFFERENT TIMES

| 0845hrs | 1145hrs | | |
|---|---|---|---|
| Average (lt/day) | Average (lt/day) | DIFFERENCE (%) | (lt/day) |
| 17314 | 18960 | 10% | 1646 |
| 0 | 0 | N/A | 0 |
| 4265 | 4230 | -1% | -35 |
| 3600 | 3575 | -1% | -25 |

MANHOLE 24A

| | 5th November | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | | | 2 | | | 3 | | |
| | Litres | Seconds | (lt/day) | Litres | Seconds | (lt/day) | Litres | Seconds | (lt/day) |
| PIPE A | Not able to monitor | | | Not able to monitor | | | Not able to monitor | | |
| PIPE B | trickle | | | trickle | | | trickle | | |
| PIPE C | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 |
| PIPE D | 0.50 | 13 | 3323 | 0.50 | 11 | 3927 | No reading | | |
| PIPE E | 0.75 | 32 | 2025 | 0.75 | 36 | 1800 | No reading | | |

| ERRORS | | | | |
|---|---|---|---|---|
| min. | max | DIFFERENCE | | Average |
| (lt / day) | | (%) | (lt/day) | (lt/day) |
| 0 | 0 | N/A | N/A | 0 |
| 0 | 0 | N/A | N/A | 0 |
| 0 | 0 | N/A | N/A | 0 |
| 3323 | 3927 | 18% | 604 | 3625 |
| 1800 | 2025 | 13% | 225 | 1913 |

# BARTON on SEA FLOW MONITORING - MANHOLES

## RAW DATA

NOTE: Some of this water is measured twice since some manholes are linked into each other

| | | MH12 | | | MH13 | | | | | | | MH15 | | | MH16A | | | MH17 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | DATE | PIPE A litres/min | PIPE B litres/min | PIPE C litres/min | PIPE A litres/min | PIPE B litres/min | PIPE C litres/min | PIPE D litres/min | PIPE E litres/min | PIPE F litres/min | PIPE G litres/min | PIPE A litres/min | PIPE B litres/min | Pipe C litres/min | PIPE A litres/min | Pipe B litres/min | Pipe C litres/min | PIPE A litres/min | PIPE B litres/min |
| 1995 | Jan | NOT MEASURED | | | | | | | | | | | | | | | | | |
| | Feb | NOT MEASURED | | | | | | | | | | | | | Includes highway drainage? | | | | |
| | Mar | NOT MEASURED | | | | | | | | | | | | | | | | | |
| | Apr | NOT MEASURED | | | | | | | | | | | | | | | | | |
| | May | 13.75 | 2.375 | 2.25 | | 3 | 2.875 | 3.625 | 2.875 | 2 | N/A | 0 | 18.225 | 0 | 52.8 | N/A | N/A | 0 | 2.5 |
| | Jun | 13.125 | 2 | 1.725 | | 2.425 | 2.125 | 4.125 | 2.375 | 2 | N/A | 15.6 | 17.625 | 0 | 49.45 | N/A | N/A | 0 | 2.5 |
| | Jul | 12.1 | 1.7 | 1.6 | | 2 | 2 | 4 | 2.2 | 1.9 | N/A | 14.975 | 15.36 | 0 | 44.22 | N/A | N/A | 0 | 2 |
| | Aug | 12.125 | 1.125 | 1 | | 2 | 2.975 | 4.125 | 2.625 | 2 | N/A | 11.325 | 11.325 | 0 | 53.9 | N/A | N/A | 0 | 1.075 |
| | Sep | 12 | 1 | 2.4 | | 1.5 | 2.9 | 4.5 | 2.5 | 2 | N/A | 7.5 | 7.5 | 0 | 42.6 | N/A | N/A | 0 | 1 |
| | Oct | 0 | 0 | 0 | | 1.55 | 2.9 | 4.575 | 2.325 | 2.5 | N/A | 0.5 | 4.725 | 0 | 35.2 | N/A | N/A | 0 | 1.025 |
| | Nov | 75 | 9.4 | 24 | | 1 | 2.5 | 4.5 | 5 | 2.5 | N/A | 0 | 33.15 | 30.975 | 35.2 | N/A | N/A | 0 | 1.5 |
| | Dec | 73.2 | 10.02 | 21.2 | | 1 | 2.5 | 4.5 | 5 | 2.5 | N/A | 0 | 35.34 | 39.78 | 35.2 | N/A | N/A | 0 | 1.58 |
| 1996 | Jan | 75 | 15 | 12 | | 1 | 2.5 | 4.5 | 5 | 2.5 | N/A | 0.5 | 33.3 | 0 | 37.55 | N/A | N/A | 0.5 | 1.275 |
| | Feb | 66 | 12.5 | 10.225 | | 1 | 2.5 | 4.5 | 5 | 2.5 | N/A | 1 | 36.65 | 0 | 45 | N/A | N/A | 0 | 1.25 |
| | Mar | 64.8 | 13.72 | 10.98 | | 1 | 2.5 | 4.5 | 5 | 2.5 | N/A | 1.056 | 45.28 | 0 | 52.26 | N/A | N/A | 0 | 1.28 |
| | Apr | 63 | 12.775 | 10 | | 1 | 2.5 | 4.5 | 5 | 2.5 | N/A | 1 | 39.25 | 0 | 49.075 | N/A | N/A | 0 | 1.3 |
| | May | NOT MEASURED | | | | | | | | | | | | | | | | | |
| | Jun | NOT MEASURED | | | | | | | | | | | | | | | | | |
| | Jul | NOT MEASURED | | | | | | | | | | | | | | | | | |
| | Aug | NOT MEASURED | | | | | | | | | | | | | | | | | |
| | Sep | NOT MEASURED | | | | | | | | | | | | | | | | | |
| | Oct | NOT MEASURED | | | | | | | | | | | | | | | | | |
| | Nov | NOT MEASURED | | | | | | | | | | | | | | | | | |
| | Dec | NOT MEASURED | | | | | | | | | | | | | | | | | |
| 1997 | Jan | | | | | | | | | | | | | | | | | | |
| | Feb | 15 | 1.5 | 0 | 0 | 1.2 | 2 | 1.7 | 1.3 | 0.7 | N/A | 0 | 3 | 1.3 | 9 | 1.3 | 4.5 | 9 | 0 |
| | Mar | 18 | 1.5 | 0 | 0 | 1.5 | 2 | 1.8 | 1.5 | 0.7 | N/A | 0 | 3 | 1.2 | 12 | 1.7 | 4 | 3 | 0 |
| | Apr | NOT MEASURED | | | | | | | | | | | | | | | | | |
| | May | 18 | 1.3 | 0 | 0 | 1.3 | 2 | 0.9 | 1.5 | 0.5 | N/A | 0 | 2.4 | 1.7 | 22.5 | 4 | 4 | 7.5 | 0 |
| | Jun | 18 | 1.4 | 0 | 0 | 0.9 | 3 | 5 | 2.2 | 1.2 | N/A | 0 | 2.4 | 2.3 | 22.5 | 0.7 | 3.8 | 10 | 0 |
| | Jul | 16.4 | 0.9 | 0 | 0 | 1.1 | 2.9 | 5 | 2.1 | 0.8 | N/A | 0 | 2.6 | 2 | 25.7 | 1.9 | 2.4 | 15 | 0 |
| | Aug | NOT MEASURED | | | | | | | | | | | | | | | | | |
| | Sep | 15 | 1.5 | 0 | 0 | 0.6 | 2.7 | 4.3 | 1.8 | 1.3 | N/A | 0 | 2.6 | 1.9 | 20 | 3.8 | 3.2 | 7.5 | 0 |
| | Oct | T MEASURED | | | | | | | | | | | | | | | | | |
| | Nov | 16.4 | 1.8 | 0 | 0 | 0.8 | 2.7 | 3.5 | 1.6 | 1.1 | N/A | 0 | 2.9 | 1.1 | 25.7 | 3.2 | 2.7 | 12 | 0 |
| | Dec | Whole area on move monitoring readings for this month distorted, monitoring discontinued and not yet restarted March 1998 | | | | | | | | | | | | | | | | | |

| | | MH18 | | MH20 | | | | | MH21 | | | | MH22A | | | MH22B | | MH22C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PIPE C litres/min | PIPE D litres/min | PIPE A litres/min | PIPE B litres/min | Pipe A litres/min | Pipe B litres/min | Pipe C litres/min | Pipe D litres/min | Pipe E litres/min | PIPE A litres/min | PIPE B litres/min | PIPE C litres/min | PIPE D litres/min | PIPE A litres/min | PIPE B litres/min | PIPE C litres/min | PIPE A litres/min | PIPE B litres/min | PIPE A litres/min |
| | | | | | | | | | | Highway? | Culverted stream? | | | | | | | |
| 2.375 | 2 | 39.55 | 0 | N/A | N/A | N/A | N/A | N/A | 5.1666667 | 15.166667 | 57.5 | 0 | 8.25 | 20.5 | 0 | 4.5 | 0 | 25.5 |
| 2.125 | 1.875 | 36.75 | 0 | N/A | N/A | N/A | N/A | N/A | 4.625 | 14.7 | 57 | 0 | 8 | 20 | 0 | 4.625 | 0 | 26.5 |
| 2.1 | 1.8 | 24.14 | 0 | N/A | N/A | N/A | N/A | N/A | 5.38 | 15 | 59.2 | 0 | 8.1 | 20 | 0 | 4.3 | 0 | 28.9 |
| 2.125 | 1.6 | 36.3 | 0 | N/A | N/A | N/A | N/A | N/A | 5.075 | 14.55 | 59.375 | 0 | 11.55 | 27.125 | 0 | 4.9 | 6.05 | 31.625 |
| 2 | 2.9 | 33.8 | 0 | N/A | N/A | N/A | N/A | N/A | 4.04 | 15.7 | 59.2 | 0 | 17 | 33.9 | 0 | 6.5 | 7.8 | 29.6 |
| 1.5 | 2.05 | 86.25 | 0.75 | N/A | N/A | N/A | N/A | N/A | 4.075 | 16 | 59.875 | 2 | 16.25 | 39.75 | 3.2 | 11 | 10.5 | 36 |
| 1.1375 | 0.975 | 29.25 | 0 | N/A | N/A | N/A | N/A | N/A | 18 | 72 | 187.5 | 23 | 21 | 40 | 3.4 | 11 | 10.5 | 36 |
| 2.71 | 2.92 | 35.25 | 0.6666667 | N/A | N/A | N/A | N/A | N/A | 18 | 72 | 300 | 30 | 21 | 40 | 3.4 | 11.5 | 11 | 40 |
| 1.175 | 3 | 36 | 1.05 | N/A | N/A | N/A | N/A | N/A | 18 | 76.5 | 330 | 30 | 21 | 42 | 4.05 | 11.25 | 11.275 | 43 |
| 1.1 | 3.225 | 36 | 1 | N/A | N/A | N/A | N/A | N/A | 19.5 | 70.5 | 315 | 41.25 | 21 | 40.5 | 5.75 | 11.25 | 11.55 | 45.5 |
| 1.18 | 3.44 | 31.74 | 1 | N/A | N/A | N/A | N/A | N/A | 21 | 65.4 | 170.6 | 30 | 20.8 | 41.4 | 5.68 | 11.78 | 11.74 | 45.48 |
| 1.125 | 3.425 | 34.35 | 1 | N/A | N/A | N/A | N/A | N/A | 21.55 | 62.925 | 150 | 30 | 21 | 40.25 | 6 | 11.6 | 11.6 | 45.2 |
| 2.4 | 2.7 | 9 | 0 | 27 | 0 | 18.8 | 12 | 0.5 | 5.2 | 22.5 | 45 | 11 | 2.7 | 50 | 0 | N/A | N/A | 37.5 |
| 2.4 | 3 | 7.5 | 0 | 67.5 | 0 | 25 | 13.1 | 0.5 | 3 | 45 | 180 | 13.5 | 9 | 60 | 0 | N/A | N/A | 75 |
| 2.3 | 3 | N/A | 0 | 27 | 0 | 18.8 | 11.3 | 0.3 | 3 | 45 | 60 | 12.5 | 6 | 50 | 0 | N/A | N/A | 50 |
| 3 | 2.4 | N/A | N/A | 30 | 0 | 18.8 | 11.3 | 0.5 | 3 | 18 | 60 | 12 | 5 | 50 | 0 | N/A | N/A | 75 |
| 3 | 2.1 | N/A | N/A | 33.8 | 0 | 18.8 | 12.9 | 0.25 | 2.4 | 22.5 | 60 | 16.4 | 5 | 60 | 0 | N/A | N/A | 45 |
| 2.3 | 2.2 | N/A | N/A | 30 | 0 | 9.4 | 11.3 | 0 | 1.8 | 8.2 | 25.7 | 10.6 | 4.3 | 52.5 | 0 | N/A | N/A | 82.5 |
| 3 | 2.5 | N/A | 0 | 24 | 0 | 7.1 | 9 | 0 | 2 | 8 | 30 | 11.3 | 5 | 37.5 | 0 | N/A | N/A | 40 |

| MH22D | | | | | | MH23 | | | | | | | MH24 | MH24A | | | | | MH24C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PIPE A litres/min | PIPE B litres/min | PIPE C litres/min | PIPE D litres/min | PIPE E litres/min | PIPE F litres/min | PIPE A litres/min | PIPE B litres/min | PIPE C litres/min | PIPE D litres/min | PIPE E litres/min | PIPE F litres/min | PIPE G litres/min | PIPE A litres/min | PIPE A litres/min | PIPE B litres/min | PIPE C litres/min | PIPE D litres/min | PIPE E litres/min | PIPE A litres/min |
| 0 | 0 | 0 | 0 | 0 | 0 | 25.625 | 0 | 0 | 0 | 0 | 0 | 0 | 0.4575 | 0 | 0 | 0 | 0 | 0 | 8 |
| 0 | 0 | 0 | 0 | 0 | 0 | 24.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0.105 | 0 | 0 | 0 | 0 | 0 | 8.125 |
| 0 | 0 | 0 | 0 | 0 | 0 | 24.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 13.12 | 11.85 | 12 | 0 | 0 | 8.5 |
| 0 | 13.9 | 13.3 | 6.3 | 4 | 3.4 | 25.875 | 8 | 11 | 0 | 0 | 0 | 0 | 0 | 7 | 5.1666667 | 5.5333333 | 6.375 | 0 | 7.8 |
| 0 | 4.26 | 2.325 | 2.5 | 1.68 | 1.06 | 22.6 | 5.9 | 9.2 | 11.7 | 4.325 | 6.575 | 2.5 | 0 | 1.96 | 1.18 | 1.72 | 1.58 | 1.26 | 10.1 |
| 0 | 2 | 0 | 1.2 | 1 | 1 | 24.25 | 7.5 | 9.375 | 7 | 4.05 | 5.65 | 3.2 | 0 | 1 | 0.5 | 1.2 | 1.2 | 1.225 | 7.875 |
| 0 | 2.025 | 0 | 1.225 | 1.2 | 1 | 47.85 | 8.45 | 7.5 | 30 | 10 | 9.125 | 0 | 0 | 1.125 | 0.6875 | 1.125 | 1.2 | 1.35 | 8.25 |
| 0 | 2.1 | 0 | 1.3 | 1.3 | 1 | 59.98 | 12.94 | 7.5 | 25.72 | 10.78 | 10.56 | 0 | 0.1 | 2.2 | 0.75 | 1.2 | 1.5 | 1.55 | 8.38 |
| 0 | 2.2 | 0 | 1.5 | 1.4 | 1.15 | 73.5 | 16.5 | 9.425 | 19.3 | 17.85 | 10.9 | 0 | 0.5 | 1.825 | 1.025 | 1.2 | 1.5 | 1.55 | 8.275 |
| 0 | 2.25 | 0 | 1.5 | 1.2 | 1.25 | 69.425 | 18.15 | 10.4 | 9.525 | 19.875 | 11.275 | 0 | 0.5 | 1.95 | 1 | 1.3 | 1.4 | 1.5 | 8.325 |
| 0 | 2.5 | 0 | 1.74 | 1.2 | 1 | 65.7 | 18.4 | 8.24 | 11.34 | 23.56 | 9.84 | 0 | 0.5 | 2.2 | 1 | 1.4 | 1.28 | 1.4 | 8.32 |
| 0 | 2.4 | 0 | 1.575 | 1.175 | 1 | 62.75 | 18 | 8.25 | 11.55 | 25 | 10.125 | 0 | 0.5 | 2.2 | 1 | 1.4 | 1.2 | 1.4 | 8.4 |
| N/A | 0.5 | 0 | 0.5 | 1 | 0 | 6 | 12 | 9.5 | 7.5 | 4 | 2.8 | 0.7 | N/A | 0 | 0 | 0 | 1.3 | 0.5 | N/A |
| N/A | 0.75 | 0 | 0.5 | 1.5 | 0.25 | 10.5 | 18 | 12 | 9 | 4 | 3 | 0.7 | N/A | 0 | 0 | 0 | 1 | 1 | N/A |
| N/A | | | | | | | | | | | | | | | | | | | |
| N/A | 0.5 | 0 | 0.5 | 1 | 0 | 8.8 | 13.8 | 9 | 7.2 | 1.7 | 2.5 | 0.5 | N/A | 0 | 0 | 0 | 1 | 0 | N/A |
| N/A | 0.5 | 0 | 0.5 | 1 | 0.25 | 8 | 13.8 | 6 | 6 | 0.6 | 2.7 | 2 | N/A | 0 | 0 | 0 | 3 | 0.9 | N/A |
| N/A | 0.25 | 0 | 0.25 | 0.5 | 0 | 10 | 6.7 | 12 | 6.3 | 0.5 | 1.9 | 0.9 | N/A | 0 | 0 | 0 | 2.1 | 1 | N/A |
| N/A | | | | | | | | | | | | | | | | | | | |
| N/A | 0.5 | 0 | 0.4 | 0.75 | 0 | 12.3 | 1 | 17.1 | 6.7 | 3.2 | 1.6 | 0.4 | N/A | 0 | 0 | 0 | 2.7 | 1.5 | N/A |
| N/A | | | | | | | | | | | | | | | | | | | |
| N/A | 0.75 | 0 | 0.5 | 1 | 0 | 12 | 0.6 | 13.8 | 5.7 | 3.2 | 1.3 | 0.25 | N/A | 0 | 0 | 0 | 2.5 | 1.3 | N/A |

# BARTON on SEA FLOW MONITORING - CATCHPITS

## RAWDATA

|  | DATE | CP12 litres/min | CP15 litres/min | CP16 litres/min | CP18 litres/min | CP20 litres/min | CP21 litres/min | CP22 litres/min | CP23 litres/min | CP24 litres/min | Totals litres/min |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1995 | Jan |  |  |  |  | NOT MEASURED |  |  |  |  |  |
|  | Feb |  |  |  |  | NOT MEASURED |  |  |  |  |  |
|  | Mar |  |  |  |  | NOT MEASURED |  |  |  |  |  |
|  | Apr |  |  |  |  | NOT MEASURED |  |  |  |  |  |
|  | May | N/A | 11.275 | 61.275 | 55.85 | N/A | 84.25 | 28 | 15.45 | N/A | 256 |
|  | Jun | N/A | 9.1325 | 59.15 | 54.025 | N/A | 83.775 | 28.5 | 17.4 | N/A | 252 |
|  | Jul | 54.28 | 9.48 | 45.86 | 54.32 | N/A | 83.9 | 27 | 16.36 | N/A | 291 |
|  | Aug | 60 | 8.45 | 29 | 55.6 | N/A | 81.625 | 28.475 | 62.575 | N/A | 326 |
|  | Sep | 60 | 7.5 | 30 | 58.3 | N/A | 79.64 | 50.8 | 31.2 | N/A | 317 |
|  | Oct | 60 | 8 | 17.1 | 64.9 | N/A | 78.625 | 51.25 | 87.675 | N/A | 368 |
|  | Nov | 60 | 8.15 | 17.1 | 77.75 | N/A | 85 | 100 | 28.5 | N/A | 377 |
|  | Dec | 60 | 8.6 | 17.1 | 80.2 | N/A | 95 | 100 | 36 | N/A | 397 |
| 1996 | Jan | 60 | 8.75 | 36 | 72.375 | N/A | 112.5 | 100 | 38.35 | N/A | 428 |
|  | Feb | 63.75 | 7.9 | 37.5 | 65.5 | N/A | 121.25 | 100 | 50.1 | N/A | 446 |
|  | Mar | 76.8 | 8.6 | 38.46 | 67.56 | N/A | 134.6 | 128 | 52.8 | N/A | 507 |
|  | Apr | 66 | 8.325 | 39.6 | 70.3 | N/A | 129.25 | 105 | 54 | N/A | 472 |
|  | May |  |  |  |  | NOT MEASURED |  |  |  |  |  |
|  | Jun |  |  |  |  | NOT MEASURED |  |  |  |  |  |
|  | Jul |  |  |  |  | NOT MEASURED |  |  |  |  |  |
|  | Aug |  |  |  |  | NOT MEASURED |  |  |  |  |  |
|  | Sep |  |  |  |  | NOT MEASURED |  |  |  |  |  |
|  | Oct |  |  |  |  | NOT MEASURED |  |  |  |  |  |
|  | Nov |  |  |  |  | NOT MEASURED |  |  |  |  |  |
|  | Dec |  |  |  |  | NOT MEASURED |  |  |  |  |  |
| 1997 | Jan |  |  |  |  | NOT MEASURED |  |  |  |  |  |
|  | Feb | 16.4 | 7 | 36 | 4.5 | 60 | 90 | 52.5 | 45 | 0 | 311 |
|  | Mar | 30 | 6 | 45 | 7.5 | 60 | 180 | 60 | 45 | 2 | 436 |
|  | Apr |  |  |  |  | NOT MEASURED |  |  |  |  |  |
|  | May | 18 | 6 | 30 | 5 | 60 | 90 | 45 | 36 | 0 | 290 |
|  | Jun | 18 | 3 | 36 | 6.4 | 60 | 90 | 45 | 36 | 0 | 294 |
|  | Jul | 16.4 | 1.8 | 36 | 7.5 | 60 | 90 | 60 | 45 | 0 | 317 |
|  | Aug |  |  |  |  | NOT MEASURED |  |  |  |  |  |
|  | Sep | 16.4 | 2.7 | 30 | 10 | 45 | 60 | 60 | 36 | 0 | 260 |
|  | Oct |  |  |  |  | NOT MEASURED |  |  |  |  |  |
|  | Nov | 12 | N/A | N/A | N/A | 45 | 60 | 36 | 30 | 0 | 183 |
|  | Dec | Whole area on move monitoring readings for this month distorted, monitoring discontinued and not yet restarted (March 1998) |  |  |  |  |  |  |  |  |  |

**BARTON on SEA FLOW MONITORING**

**ESTIMATE OF TOTAL FLOW ALONG THIS SECTION OF CLIFF FROM MANHOLES ONLY**

|  | DATE | MH12 PIPE A litres/min | PIPE B litres/min | PIPE C litres/min | MH13 PIPE A litres/min | PIPE B litres/min | PIPE C litres/min | PIPE D litres/min | PIPE E litres/min | PIPE F litres/min | PIPE G litres/min | MH15 PIPE A litres/min | PIPE B litres/min | Pipe C litres/min | MH16A PIPE A litres/min | Pipe B litres/min | Pipe C litres/min | MH17 PIPE A litres/min | PIPE B litres/min | PIPE C litres/min |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1995 | Jan |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Feb |  |  |  |  |  |  |  |  |  |  |  |  |  | Includes |  |  |  |  |  |
|  | Mar |  |  |  |  |  |  |  |  |  |  |  |  |  | highway |  |  |  |  |  |
|  | Apr |  |  |  |  |  |  |  |  |  |  |  |  |  | drainage? |  |  |  |  |  |
|  | May | 13.75 | 2.375 | 2.25 | 'Got by MH 15 and MH12 |  |  |  |  |  | N/A | 0 | 18.225 | 0 | 52.8 | N/A | N/A | Got by MH 16A |  |  |
|  | Jun | 13.125 | 2 | 1.725 |  |  |  |  |  |  | N/A | 15.6 | 17.625 | 0 | 49.45 | N/A | N/A |  |  |  |
|  | Jul | 12.1 | 1.7 | 1.6 |  |  |  |  |  |  | N/A | 14.975 | 15.36 | 0 | 44.22 | N/A | N/A |  |  |  |
|  | Aug | 12.125 | 1.125 | 1 |  |  |  |  |  |  | N/A | 11.325 | 11.325 | 0 | 53.9 | N/A | N/A |  |  |  |
|  | Sep | 12 | 1 | 2.4 |  |  |  |  |  |  | N/A | 7.5 | 7.5 | 0 | 42.6 | N/A | N/A |  |  |  |
|  | Oct | 0 | 0 | 0 |  |  |  |  |  |  | N/A | 0.5 | 4.725 | 0 | 35.2 | N/A | N/A |  |  |  |
|  | Nov | 75 | 9.4 | 24 |  |  |  |  |  |  | N/A | 0 | 33.15 | 30.975 | 35.2 | N/A | N/A |  |  |  |
|  | Dec | 73.2 | 10.02 | 21.2 |  |  |  |  |  |  | N/A | 0 | 35.34 | 39.78 | 35.2 | N/A | N/A |  |  |  |
| 1996 | Jan | 75 | 15 | 12 |  |  |  |  |  |  | N/A | 0.5 | 33.3 | 0 | 37.55 | N/A | N/A |  |  |  |
|  | Feb | 66 | 12.5 | 10.225 |  |  |  |  |  |  | N/A | 1 | 36.65 | 0 | 45 | N/A | N/A |  |  |  |
|  | Mar | 64.8 | 13.72 | 10.98 |  |  |  |  |  |  | N/A | 1.056 | 45.28 | 0 | 52.26 | N/A | N/A |  |  |  |
|  | Apr | 63 | 12.775 | 10 |  |  |  |  |  |  | N/A | 1 | 39.25 | 0 | 49.075 | N/A | N/A |  |  |  |
|  | May | NOT MEASURED |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Jun | NOT MEASURED |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Jul | NOT MEASURED |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Aug | NOT MEASURED |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Sep | NOT MEASURED |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Oct | NOT MEASURED |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Nov | NOT MEASURED |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Dec | NOT MEASURED |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1997 | Jan | NOT MEASURED |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Feb | 15 | 1.5 | 0 |  |  |  |  |  |  | N/A | 0 | 3 | 1.3 | 9 | 1.3 | 4.5 |  |  |  |
|  | Mar | 18 | 1.5 | 0 |  |  |  |  |  |  | N/A | 0 | 3 | 1.2 | 12 | 1.7 | 4 |  |  |  |
|  | Apr | NOT MEASURED |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | May | 18 | 1.3 | 0 |  |  |  |  |  |  | N/A | 0 | 2.4 | 1.7 | 22.5 | 4 | 4 |  |  |  |
|  | Jun | 18 | 1.4 | 0 |  |  |  |  |  |  | N/A | 0 | 2.4 | 2.3 | 22.5 | 0.7 | 3.8 |  |  |  |
|  | Jul | 16.4 | 0.9 | 0 |  |  |  |  |  |  | N/A | 0 | 2.6 | 2 | 25.7 | 1.9 | 2.4 |  |  |  |
|  | Aug | NOT MEASURED |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Sep | 15 | 1.5 | 0 |  |  |  |  |  |  | N/A | 0 | 2.6 | 1.9 | 20 | 3.8 | 3.2 |  |  |  |
|  | Oct | NOT MEASURED |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Nov | 16.4 | 1.8 | 0 |  |  |  |  |  |  | N/A | 0 | 2.9 | 1.1 | 25.7 | 3.2 | 2.7 |  |  |  |
|  | Dec | Whole area on move monitoring readings for this month distorted, monitoring discontinued and not yet restarted March 1998 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

| | MH18 | | MH20 | | | | | MH21 | | | | MH22A | | | MH22B | | MH22C | MH22D | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PIPE D litres/min | PIPE A litres/min | PIPE B litres/min | Pipe A litres/min | Pipe B litres/min | Pipe C litres/min | Pipe D litres/min | Pipe E litres/min | PIPE A litres/min | PIPE B litres/min | PIPE C litres/min | PIPE D litres/min | PIPE A litres/min | PIPE B litres/min | PIPE C litres/min | PIPE A litres/min | PIPE B litres/min | PIPE A litres/min | PIPE A litres/min | PIPE B litres/min |
| | | | | | | | | | Highway? | Culverted stream? | | | | | | | | | |
| | 39.55 | 0 | N/A | N/A | N/A | N/A | N/A | 5.1666667 | 15.166667 | 57.5 | 0 | 8.25 | 20.5 | 0 | got by 22a | | got by 22a | | |
| | 36.75 | 0 | N/A | N/A | N/A | N/A | N/A | 4.625 | 14.7 | 57 | 0 | 8 | 20 | 0 | | | | | |
| | 24.14 | 0 | N/A | N/A | N/A | N/A | N/A | 5.38 | 15 | 59.2 | 0 | 8.1 | 20 | 0 | | | | | |
| | 36.3 | 0 | N/A | N/A | N/A | N/A | N/A | 5.075 | 14.55 | 59.375 | 0 | 11.55 | 27.125 | 0 | | | | | |
| | 33.8 | 0 | N/A | N/A | N/A | N/A | N/A | 4.04 | 15.7 | 59.2 | 0 | 17 | 33.9 | 0 | | | | | |
| | 86.25 | 0.75 | N/A | N/A | N/A | N/A | N/A | 4.075 | 16 | 59.875 | 2 | 16.25 | 39.75 | 3.2 | | | | | |
| | 29.25 | 0 | N/A | N/A | N/A | N/A | N/A | 18 | 72 | 187.5 | 23 | 21 | 40 | 3.4 | | | | | |
| | 35.25 | 0.6666667 | N/A | N/A | N/A | N/A | N/A | 18 | 72 | 300 | 30 | 21 | 40 | 3.4 | | | | | |
| | 36 | 1.05 | N/A | N/A | N/A | N/A | N/A | 18 | 76.5 | 330 | 30 | 21 | 42 | 4.05 | | | | | |
| | 36 | 1 | N/A | N/A | N/A | N/A | N/A | 19.5 | 70.5 | 315 | 41.25 | 21 | 40.5 | 5.75 | | | | | |
| | 31.74 | 1 | N/A | N/A | N/A | N/A | N/A | 21 | 65.4 | 170.6 | 30 | 20.8 | 41.4 | 5.68 | | | | | |
| | 34.35 | 1 | N/A | N/A | N/A | N/A | N/A | 21.55 | 62.925 | 150 | 30 | 21 | 40.25 | 6 | | | | | |
| | 9 | 0 | 27 | 0 | 18.8 | 12 | 0.5 | 5.2 | 22.5 | 45 | 11 | 2.7 | 50 | 0 | | | | | |
| | 7.5 | 0 | 67.5 | 0 | 25 | 13.1 | 0.5 | 3 | 45 | 180 | 13.5 | 9 | 60 | 0 | | | | | |
| | N/A | 0 | 27 | 0 | 18.8 | 11.3 | 0.3 | 3 | 45 | 60 | 12.5 | 6 | 50 | 0 | | | | | |
| | N/A | N/A | 30 | 0 | 18.8 | 11.3 | 0.5 | 3 | 18 | 60 | 12 | 5 | 50 | 0 | | | | | |
| | N/A | N/A | 33.8 | 0 | 18.8 | 12.9 | 0.25 | 2.4 | 22.5 | 60 | 16.4 | 5 | 60 | 0 | | | | | |
| | N/A | N/A | 30 | 0 | 9.4 | 11.3 | 0 | 1.8 | 8.2 | 25.7 | 10.6 | 4.3 | 52.5 | 0 | | | | | |
| | N/A | 0 | 24 | 0 | 7.1 | 9 | 0 | 2 | 8 | 30 | 11.3 | 5 | 37.5 | 0 | | | | | |

| PIPE C litres/min | PIPE D litres/min | PIPE E litres/min | PIPE F litres/min | MH23 PIPE A litres/min | PIPE B litres/min | PIPE C litres/min | PIPE D litres/min | PIPE E litres/min | PIPE F litres/min | PIPE G litres/min | MH24 PIPE A litres/min | MH24A PIPE A litres/min | PIPE B litres/min | PIPE C litres/min | PIPE D litres/min | PIPE E litres/min | MH24C PIPE A litres/min | Totals litres/min |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | UNSURE WHERE THIS FLOWS TOO | | | | | | | |
| got by 22a | | | | 25.625 | 0 | 0 | 0 | 0 | 0 | 0 | 0.4575 | 0 | 0 | 0 | 0 | 0 | 8 | 270 |
| | | | | 24.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0.105 | 0 | 0 | 0 | 0 | 0 | 8.125 | 273 |
| | | | | 24.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 13.12 | 11.85 | 12 | 0 | 0 | 8.5 | 292 |
| | | | | 25.875 | 8 | 11 | 0 | 0 | 0 | 0 | 0 | 7 | 5.1666667 | 5.5333333 | 6.375 | 0 | 7.8 | 322 |
| | | | | 22.6 | 5.9 | 9.2 | 11.7 | 4.325 | 6.575 | 2.5 | 0 | 1.96 | 1.18 | 1.72 | 1.58 | 1.26 | 10.1 | 317 |
| | | | | 24.25 | 7.5 | 9.375 | 7 | 4.05 | 5.65 | 3.2 | 0 | 1 | 0.5 | 1.2 | 1.2 | 1.225 | 7.875 | 343 |
| | | | | 47.85 | 8.45 | 7.5 | 30 | 10 | 9.125 | 0 | 0 | 1.125 | 0.6875 | 1.125 | 1.2 | 1.35 | 8.25 | 729 |
| | | | | 59.98 | 12.94 | 7.5 | 25.72 | 10.78 | 10.56 | 0 | 0.1 | 2.2 | 0.75 | 1.2 | 1.5 | 1.55 | 8.38 | 878 |
| | | | | 73.5 | 16.5 | 9.425 | 19.3 | 17.85 | 10.9 | 0 | 0.5 | 1.825 | 1.025 | 1.2 | 1.5 | 1.55 | 8.275 | 895 |
| | | | | 69.425 | 18.15 | 10.4 | 9.525 | 19.875 | 11.275 | 0 | 0.5 | 1.95 | 1 | 1.3 | 1.4 | 1.5 | 8.325 | 877 |
| | | | | 65.7 | 18.4 | 8.24 | 11.34 | 23.56 | 9.84 | 0 | 0.5 | 2.2 | 1 | 1.4 | 1.28 | 1.4 | 8.32 | 729 |
| | | | | 62.75 | 18 | 8.25 | 11.55 | 25 | 10.125 | 0 | 0.5 | 2.2 | 1 | 1.4 | 1.2 | 1.4 | 8.4 | 694 |
| | | | | 6 | 12 | 9.5 | 7.5 | 4 | 2.8 | 0.7 | N/A | 0 | 0 | 0 | 1.3 | 0.5 | | 284 |
| | | | | 10.5 | 18 | 12 | 9 | 4 | 3 | 0.7 | N/A | 0 | 0 | 0 | 1 | 1 | | 525 |
| | | | | 8.8 | 13.8 | 9 | 7.2 | 1.7 | 2.5 | 0.5 | N/A | 0 | 0 | 0 | 1 | 0 | | 332 |
| | | | | 8 | 13.8 | 6 | 6 | 0.6 | 2.7 | 2 | N/A | 0 | 0 | 0 | 3 | 0.9 | | 303 |
| | | | | 10 | 6.7 | 12 | 6.3 | 0.5 | 1.9 | 0.9 | N/A | 0 | 0 | 0 | 2.1 | 1 | | 325 |
| | | | | 12.3 | 1 | 17.1 | 6.7 | 3.2 | 1.6 | 0.4 | N/A | 0 | 0 | 0 | 2.7 | 1.5 | | 248 |
| | | | | 12 | 0.6 | 13.8 | 5.7 | 3.2 | 1.3 | 0.25 | N/A | 0 | 0 | 0 | 2.5 | 1.3 | | 228 |

## BARTON on SEA FLOW MONITORING

## ESTIMATE OF TOTAL FLOW ALONG THIS SECTION OF CLIFF FROM CATCHPITS WITH SOME SYNTHESIZED DATA AND, COMPARISON TO TOTAL FLOWS AS CALCULATED BY MANHOLES VS CATCHPITS.

| | | | | | | | | | | | | TOTALS | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | DATE | CP12 litres/min | CP15 litres/min | CP16 litres/min | CP18 litres/min | CP20 litres/min | CP21 litres/min | CP22 litres/min | CP23 litres/min | CP24 litres/min | MH24 litres/min | Catchpits litres/min | Manholes litres/min | Difference litres/min | Comments |
| 1995 | Jan | NOT MEASURED | | | | | | | | | | | | | |
| | Feb | NOT MEASURED | | | | | | | | | | | | | |
| | Mar | NOT MEASURED | | | | | | | | | | | | | |
| | Apr | NOT MEASURED | | | | | | | | | | | | | |
| | May | 60 | 11.275 | 61.275 | 55.85 | 60 | 84.25 | 28 | 15.45 | 0.4575 | 0 | 377 | 270 | -107 | Suspect Not all manholes monitored |
| | Jun | 60 | 9.1325 | 59.15 | 54.025 | 60 | 83.775 | 28.5 | 17.4 | 0.105 | 0 | 372 | 273 | -99 | Suspect Not all manholes monitored |
| | Jul | 54.28 | 9.48 | 45.86 | 54.32 | 60 | 83.9 | 27 | 16.36 | 0 | 36.97 | 388 | 292 | -96 | Suspect Not all manholes monitored |
| | Aug | 60 | 8.45 | 29 | 55.6 | 60 | 81.625 | 28.475 | 62.575 | 0 | 24.075 | 410 | 322 | -88 | Suspect Not all manholes monitored |
| | Sep | 60 | 7.5 | 30 | 58.3 | 60 | 79.64 | 50.8 | 31.2 | 0 | 7.7 | 385 | 317 | -68 | Suspect Not all manholes monitored |
| | Oct | 60 | 8 | 17.1 | 64.9 | 60 | 78.625 | 51.25 | 87.675 | 0 | 5.125 | 433 | 343 | -90 | Suspect Not all manholes monitored |
| | Nov | 60 | 8.15 | 17.1 | 77.75 | 60 | 85 | 100 | 28.5 | 0 | 5.4875 | 442 | 729 | 287 | Suspect Not all manholes monitored |
| | Dec | 60 | 8.6 | 17.1 | 80.2 | 60 | 95 | 100 | 36 | 0.1 | 7.2 | 464 | 878 | 414 | Suspect Not all manholes monitored |
| 1996 | Jan | 60 | 8.75 | 36 | 72.375 | 60 | 112.5 | 100 | 38.35 | 0.5 | 7.1 | 496 | 895 | 400 | Suspect Not all manholes monitored |
| | Feb | 63.75 | 7.9 | 37.5 | 65.5 | 60 | 121.25 | 100 | 50.1 | 0.5 | 7.15 | 514 | 877 | 363 | Suspect Not all manholes monitored |
| | Mar | 76.8 | 8.6 | 38.46 | 67.56 | 60 | 134.6 | 128 | 52.8 | 0.5 | 7.28 | 575 | 729 | 154 | Suspect Not all manholes monitored |
| | Apr | 66 | 8.325 | 39.6 | 70.3 | 60 | 129.25 | 105 | 54 | 0.5 | 7.2 | 540 | 694 | 154 | Suspect Not all manholes monitored |
| | May | NOT MEASURED | | | | | | | | | | | | | |
| | Jun | NOT MEASURED | | | | | | | | | | | | | |
| | Jul | NOT MEASURED | | | | | | | | | | | | | |
| | Aug | NOT MEASURED | | | | | | | | | | | | | |
| | Sep | NOT MEASURED | | | | | | | | | | | | | |
| | Oct | NOT MEASURED | | | | | | | | | | | | | |
| | Nov | NOT MEASURED | | | | | | | | | | | | | |
| | Dec | NOT MEASURED | | | | | | | | | | | | | |
| 1997 | Jan | NOT MEASURED | | | | | | | | | | | | | |
| | Feb | 16.4 | 7 | 36 | 4.5 | 60 | 90 | 52.5 | 45 | 0 | 1.8 | 313 | 284 | -30 | Good |
| | Mar | 30 | 6 | 45 | 7.5 | 60 | 180 | 60 | 45 | 2 | 2 | 438 | 525 | 87 | OK |
| | Apr | NOT MEASURED | | | | | | | | | | | | | |
| | May | 18 | 6 | 30 | 5 | 60 | 90 | 45 | 36 | 0 | 1 | 291 | 332 | 41 | OK |
| | Jun | 18 | 3 | 36 | 6.4 | 60 | 90 | 45 | 36 | 0 | 3.9 | 298 | 303 | 4 | Good |
| | Jul | 16.4 | 1.8 | 36 | 7.5 | 60 | 90 | 60 | 45 | 0 | 3.1 | 320 | 325 | 6 | Good |
| | Aug | NOT MEASURED | | | | | | | | | | | | | |
| | Sep | 16.4 | 2.7 | 30 | 10 | 45 | 60 | 60 | 36 | 0 | 4.2 | 264 | 248 | -16 | Good |
| | Oct | NOT MEASURED | | | | | | | | | | | | | |
| | Nov | 12 | 3 | 30 | 10 | 45 | 60 | 36 | 30 | 0 | 3.8 | 230 | 228 | -1 | Good |
| | Dec | Whole area on move monitoring readings for this month distorted, monitoring discontinued and not yet restarted (March 1998) | | | | | | | | | | | | | |

Key

▭ = Synthesized values

# BARTON on SEA FLOW MONITORING - MOLE DRAINS ONLY
# ESTIMATE OF TOTAL FLOW ALONG THIS SECTION FROM MOLE DRAINS

| | | MH13 | | | | | MH17 | | | MH22D | | | | | MH23 | | | | | MH24A | | | | | Totals |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | DATE | PIPE B litres/min | PIPE C litres/min | PIPE D litres/min | PIPE E litres/min | PIPE F litres/min | PIPE B litres/min | PIPE C litres/min | PIPE D litres/min | PIPE B litres/min | PIPE C litres/min | PIPE D litres/min | PIPE E litres/min | PIPE F litres/min | PIPE B litres/min | PIPE C litres/min | PIPE D litres/min | PIPE E litres/min | PIPE F litres/min | PIPE A litres/min | PIPE B litres/min | PIPE C litres/min | PIPE D litres/min | PIPE E litres/min | litres/min |
| 1995 | Jan | NOT MEASURED | | | | | | | | | | | | | | | | | | | | | | | |
| | Feb | NOT MEASURED | | | | | | | | | | | | | | | | | | | | | | | |
| | Mar | NOT MEASURED | | | | | | | | | | | | | | | | | | | | | | | |
| | Apr | NOT MEASURED | | | | | | | | | | | | | | | | | | | | | | | |
| | May | 3 | 2.875 | 3.625 | 2.875 | 2 | 2.5 | 2.375 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 21 |
| | Jun | 2.425 | 2.125 | 4.125 | 2.375 | 2 | 2.5 | 2.125 | 1.875 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 |
| | Jul | 2 | 2 | 4 | 2.2 | 1.9 | 2 | 2.1 | 1.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 13.12 | 11.85 | 12 | 0 | 0 | 55 |
| | Aug | 2 | 2.975 | 4.125 | 2.625 | 2 | 1.075 | 2.125 | 1.6 | 13.9 | 13.3 | 6.3 | 4 | 3.4 | 8 | 11 | 0 | 0 | 0 | 7 | 5.16667 | 5.53333 | 6.375 | 0 | 103 |
| | Sep | 1.5 | 2.9 | 4.5 | 2.5 | 2 | 1 | 2 | 2.9 | 4.26 | 2.325 | 2.5 | 1.68 | 1.06 | 5.9 | 9.2 | 11.7 | 4.325 | 6.575 | 1.96 | 1.18 | 1.72 | 1.58 | 1.26 | 77 |
| | Oct | 1.55 | 2.9 | 4.575 | 2.325 | 2.5 | 1.025 | 1.5 | 2.05 | 2 | 0 | 1.2 | 1 | 1 | 7.5 | 9.375 | 7 | 4.05 | 5.65 | 1 | 0.5 | 1.2 | 1.2 | 1.225 | 62 |
| | Nov | 1 | 2.5 | 4.5 | 5 | 2.5 | 1.5 | 1.1375 | 0.975 | 2.025 | 0 | 1.225 | 1.2 | 1 | 8.45 | 7.5 | 30 | 10 | 9.125 | 1.125 | 0.6875 | 1.125 | 1.2 | 1.35 | 95 |
| | Dec | 1 | 2.5 | 4.5 | 5 | 2.5 | 1.58 | 2.71 | 2.92 | 2.1 | 0 | 1.3 | 1.3 | 1 | 12.94 | 7.5 | 25.72 | 10.78 | 10.56 | 2.2 | 0.75 | 1.2 | 1.5 | 1.55 | 103 |
| 1996 | Jan | 1 | 2.5 | 4.5 | 5 | 2.5 | 1.275 | 1.175 | 3 | 2.2 | 0 | 1.5 | 1.4 | 1.15 | 16.5 | 9.425 | 19.3 | 17.85 | 10.9 | 1.825 | 1.025 | 1.2 | 1.5 | 1.55 | 108 |
| | Feb | 1 | 2.5 | 4.5 | 5 | 2.5 | 1.25 | 1.1 | 3.225 | 2.25 | 0 | 1.5 | 1.2 | 1.25 | 18.15 | 10.4 | 9.525 | 19.875 | 11.275 | 1.95 | 1 | 1.3 | 1.4 | 1.5 | 104 |
| | Mar | 1 | 2.5 | 4.5 | 5 | 2.5 | 1.28 | 1.18 | 3.44 | 2.5 | 0 | 1.74 | 1.2 | 1 | 18.4 | 8.24 | 11.34 | 23.56 | 9.84 | 2.2 | 1 | 1.4 | 1.28 | 1.4 | 107 |
| | Apr | 1 | 2.5 | 4.5 | 5 | 2.5 | 1.3 | 1.125 | 3.425 | 2.4 | 0 | 1.575 | 1.175 | 1 | 18 | 8.25 | 11.55 | 25 | 10.125 | 2.2 | 1 | 1.4 | 1.2 | 1.4 | 108 |
| | May | NOT MEASURED | | | | | | | | | | | | | | | | | | | | | | | |
| | Jun | NOT MEASURED | | | | | | | | | | | | | | | | | | | | | | | |
| | Jul | NOT MEASURED | | | | | | | | | | | | | | | | | | | | | | | |
| | Aug | NOT MEASURED | | | | | | | | | | | | | | | | | | | | | | | |
| | Sep | NOT MEASURED | | | | | | | | | | | | | | | | | | | | | | | |
| | Oct | NOT MEASURED | | | | | | | | | | | | | | | | | | | | | | | |
| | Nov | NOT MEASURED | | | | | | | | | | | | | | | | | | | | | | | |
| | Dec | NOT MEASURED | | | | | | | | | | | | | | | | | | | | | | | |
| 1997 | Jan | NOT MEASURED | | | | | | | | | | | | | | | | | | | | | | | |
| | Feb | 1.2 | 2 | 1.7 | 1.3 | 0.7 | 0 | 2.4 | 2.7 | 0.5 | 0 | 0.5 | 1 | 0 | 12 | 9.5 | 7.5 | 4 | 2.8 | 0 | 0 | 0 | 1.3 | 0.5 | 52 |
| | Mar | 1.5 | 2 | 1.8 | 1.5 | 0.7 | 0 | 2.4 | 3 | 0.75 | 0 | 0.5 | 1.5 | 0.25 | 18 | 12 | 9 | 4 | 3 | 0 | 0 | 0 | 1 | 1 | 64 |
| | Apr | NOT MEASURED | | | | | | | | | | | | | | | | | | | | | | | |
| | May | 1.3 | 2 | 0.9 | 1.5 | 0.5 | 0 | 2.3 | 3 | 0.5 | 0 | 0.5 | 1 | 0 | 13.8 | 9 | 7.2 | 1.7 | 2.5 | 0 | 0 | 0 | 1 | 0 | 49 |
| | Jun | 0.9 | 3 | 5 | 2.2 | 1.2 | 0 | 3 | 2.4 | 0.5 | 0 | 0.5 | 1 | 0.25 | 13.8 | 6 | 6 | 0.6 | 2.7 | 0 | 0 | 0 | 3 | 0.9 | 53 |
| | Jul | 1.1 | 2.9 | 5 | 2.1 | 0.8 | 0 | 3 | 2.1 | 0.25 | 0 | 0.25 | 0.5 | 0 | 6.7 | 12 | 6.3 | 0.5 | 1.9 | 0 | 0 | 0 | 2.1 | 1 | 49 |
| | Aug | NOT MEASURED | | | | | | | | | | | | | | | | | | | | | | | |
| | Sep | 0.6 | 2.7 | 4.3 | 1.8 | 1.3 | 0 | 2.3 | 2.2 | 0.5 | 0 | 0.4 | 0.75 | 0 | 1 | 17.1 | 6.7 | 3.2 | 1.6 | 0 | 0 | 0 | 2.7 | 1.5 | 51 |
| | Oct | NOT MEASURED | | | | | | | | | | | | | | | | | | | | | | | |
| | Nov | 0.8 | 2.7 | 3.5 | 1.6 | 1.1 | 0 | 3 | 2.5 | 0.75 | 0 | 0.5 | 1 | 0 | 0.6 | 13.8 | 5.7 | 3.2 | 1.3 | 0 | 0 | 0 | 2.5 | 1.3 | 46 |
| | Dec | Whole area on move monitoring readings for this month distorted, monitoring discontinued and not yet restarted (March 1998) | | | | | | | | | | | | | | | | | | | | | | | |

# APPENDIX D

Project Plan

Budget

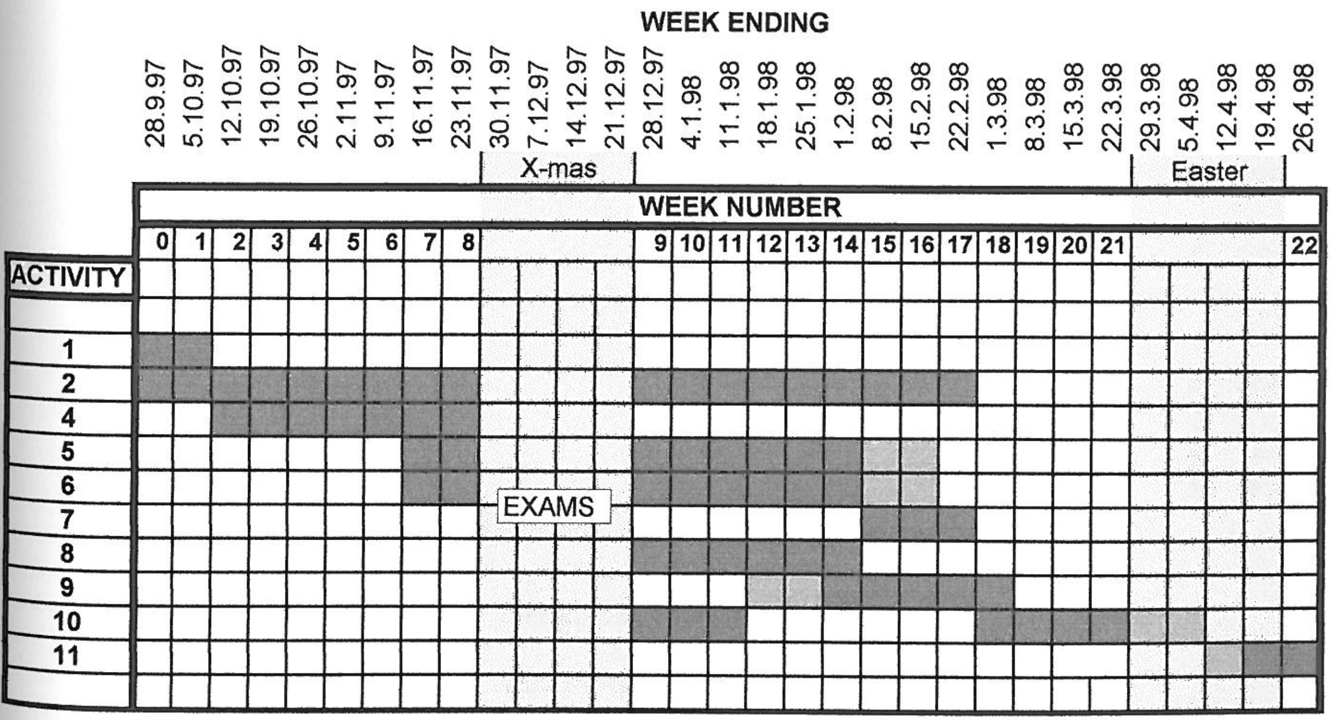
Minutes

# GROUP PROJECT REVIEW FORM

Project Title: MOLE DRAINS
Team : Richard Drury, Louis Le Pen

Breakdown of tasks;

1 Set objectives.
2 Read relevant literature & Compare with other drainage methods.
3 Study geology and topography of Barton-on-Sea.
4 Study New Forest D.C. Monitoring data.
5 Develop a Water Balance Analysis for the Cliff Area.
6 Develop a Slope Stability Analysis for the Undercliff.
7 Analyze and assess effectiveness of mole drains.
8 Develop a cost effective flow monitoring system for mole drain outfalls.
9 Draft Write up.
10 Final Write up.
11 Final edit and binding



WEEK ENDING

| | 28.9.97 | 5.10.97 | 12.10.97 | 19.10.97 | 26.10.97 | 2.11.97 | 9.11.97 | 16.11.97 | 23.11.97 | 30.11.97 | 7.12.97 | 14.12.97 | 21.12.97 | 28.12.97 | 4.1.98 | 11.1.98 | 18.1.98 | 25.1.98 | 1.2.98 | 8.2.98 | 15.2.98 | 22.2.98 | 1.3.98 | 8.3.98 | 15.3.98 | 22.3.98 | 29.3.98 | 5.4.98 | 12.4.98 | 19.4.98 | 26.4.98 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | X-mas | | | | | | | | | | | | | | | | | Easter | | | | |
| | WEEK NUMBER | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | | | | | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | | | | | 22 |
| ACTIVITY | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1 | ▨ | ▨ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | | | | | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | | | | | | | | | |
| 4 | | | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | | | | | | | | | | | | | | | | | | | | | | |
| 5 | | | | | | | | ▨ | ▨ | | | | | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ░ | ░ | | | | | | | | | | |
| 6 | | | | | | | | ▨ | ▨ | | | | | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ░ | ░ | | | | | | | | | | |
| 7 | | | | | | | | | | | EXAMS | | | | | | | | | ▨ | ▨ | ▨ | | | | | | | | | |
| 8 | | | | | | | | | | | | | | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | | | | | | | | | | | | |
| 9 | | | | | | | | | | | | | | | | | ░ | ░ | ▨ | ▨ | ▨ | ▨ | ▨ | | | | | | | | |
| 10 | | | | | | | | | | | | | | ▨ | ▨ | ▨ | | | | | | | ▨ | ▨ | ▨ | ▨ | ░ | ░ | | | |
| 11 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | ░ | ▨ | ▨ |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

# BUDGET PLAN: 1997/98 GDP - MOLE DRAINS

|  | Total No. | NFDC | GDP Group | Cost per Item | Cost to Group |
|---|---|---|---|---|---|
| **Printing** |  |  |  |  |  |
| Research |  |  |  |  |  |
| Reports | 25 | 15 | 10 | £ 1.50 | £ 15.00 |
| Data | - | Yes | - | £ - | - |
| Drawing Plots | 10 | 9 | 1 | £ 2.00 | £ 2.00 |
| OS maps | 2 | - | 2 | £ 38.00 | £ 76.00 |
| General Maps | 1 | - | 1 | £ 5.00 | £ 5.00 |
| Colour Copying |  | - | 80 | £ 1.00 | £ 80.00 |
| Final Report (200 page @ 3p/page = £6/copy + £3 binding) |  |  |  |  |  |
| Group Members | 3 | 1 | 2 | £ 9.00 | £ 18.00 |
| MEng Office | 3 | 0 | 3 | £ 9.00 | £ 27.00 |
| Others | 1 | 0 | 0 | £ 9.00 | £ 9.00 |
| **Stationary** |  |  |  |  |  |
| Graph Paper |  | A4: | 1 | £ 2.00 | £ 2.00 |
|  |  | A3: | 1 | £ 2.00 | £ 2.00 |
| Folders |  | A4: | 10 | £ 0.50 | £ 5.00 |
| Printer Ink Cartridges | (Cost of ink covered in printing) | B & W: | 2 | £ 13.00 | - |
|  |  | Colour: | 2 | £ 15.00 | - |
| Telephone | Free service |  |  |  | £ - |
| Fax | Free service |  |  |  | £ - |
| Photocopying | Free service |  |  |  | £ - |
| **Presentation** |  |  |  |  |  |
| Refreshments |  |  |  |  | £ 35.00 |
| OHP's & Slides |  |  |  |  | £ 30.00 |
| **Consultant** |  |  | 0 hours |  | £ - |
| **Travel Expenditure** |  |  |  |  |  |
| Site Visit: Barton-on-Sea | 5 No. | Travel | 225 | miles | £ 57.25 |
|  |  | Parking |  |  | £ - |
| NFDC Head Office | 4 No. | Travel | 160 | miles | £ 42.30 |
| General use - |  | Travel | 60 | miles | £ 19.30 |

|  |  |
|---|---|
| **TOTAL EXPENDITURE** | **£ 424.85** |
| **ALLOWABLE BUDGET** | **£ 525.00** |
| **TOTAL - BUDGET** | **£ 100.15** |

## Minutes from GDP meeting Thurs 26th Sept

Commenced at: 4pm Duration: 1hour 30mins

Those present : Louis Le Pen
Richard Drury
Dr Barton (Supervisor)

Items Discussed:

Background reading.

Topics to search for literature about.

The type of study to be undertaken.

Making contact with NFDC.

Setting a slot for regular meetings between group and supervisor.

The possible automation of flow monitoring for the Mole Drains.

Travel expenses.

Actions Resulting and Any Reports Made:

Team members agreed to familiarise themselves with basic seepage theory, a number of books were recommended by Dr Barton.

Dr Barton gave some ideas about where to start searching the literature from (key words).

It was broadly agreed that the study would be field work based.

It was decided that the group should meet with the NFDC a.s.a.p. in order to discover exactly what information they could provide. To facilitate this Dr Barton provided a contact number.

Richard Drury agreed to investigate the possibility of an electronic flow monitoring system for the Mole Drains.

Louis Le Pen agreed to investigate the possible purchase of a 1:1250 scale OS map and also to write up minutes.
Weekly slot Monday at 10am allocated for meetings between students and supervisor. The first meeting to commence on the 13th October.

Telephone numbers and addresses were exchanged.

Dr Barton agreed that some form of compensation was appropriate for travel expenses to and from the study area.

Richard and Louis agreed slots on Mondays and Fridays when they could meet if required to discuss project progress.

## Minutes from GDP meeting Monday 30th September

Commenced at: 12noon Duration: 30mins

Those present : Louis Le Pen
Richard Drury
Dr Barton (Supervisor)

Items discussed:

Objectives for the project - filling out group project authorisation form.

Questions to ask NFDC for meeting set up for Tuesday 31st September at their HQ.

Actions Resulting and Any Reports Made:

Preliminary list of objectives drawn up.

After discussion the project authorisation form was filled out, Richard agreed to get this signed and a copy to be circulated to the team members and supervisor.

List of questions drawn up for said meeting.

## Minutes for GDP meeting with NFDC Tuesday 31st September.

Commenced at: 11.30am Duration: 1hours 45mins

Those present : Louis Le Pen
Richard Drury
Andrew Bradbury (Engineer NFDC)
Steve Cook (Engineer NFDC)

Items discussed:

Exact location of Mole Drains.

Rainfall data.

Geological data.

Logged piezometer readings.

Flow monitoring.

Possible electronic monitoring system for Mole Drains.

Any other information the NFDC possesses which could be made available to the project.

What were the NFDC looking to get out of the project?

Actions Resulting and Any Reports Made:

NFDC reported that they did not have precise locations for the mole drains, though during installation the mole pipeline had been precisely located and guided to its intended position. They would therefore attempt to ascertain what had happened to this information.

NFDC reported that the contractor was A.E. Bartholomew and that they did not know if other Mole Drains had been installed for other clients.

NFDC reported that rainfall and geological data was abundant and would provide the group with all that they had.

With regard to flow monitoring NFDC confirmed that records do exist but that they are infrequent, being only monthly at best. Though some weekly readings do exist from the very beginning of the project (1994). All records would be made available to the group.

NFDC reported that piezometers are only installed at one location and that water levels were not currently being logged, though they had been in the past and agreed to make these records available to us.

NFDC stated that without attending a three day working in confined spaces health and safety training scheme the group would not be able to work in the mole drains without trained NFDC staff present. Therefore the group agreed that the next time that the NFDC monitored the drains the two group members would come along. This ruled out the possibility of the GDP team members monitoring flow rates themselves.

NFDC stated that they would be interested in any electronic monitoring system that the group could come up with, though funding was unlikely to be available for it this fiscal year.

NFDC provided the team with some information that they had gathered together prior to the meeting regarding monitoring of the mole drains, and agreed to send additional information requested to Dr Barton by the end of the following week.

With regard to what they would like to get out of the project, after extensive discussions two main areas of interest were ascertained. Firstly the design of a method for the optimum placing of new Mole drains, and secondly the design of a practical cost effective electronic flow monitoring system for the Mole Drains. The second of these to eliminate the current need for a costly 2 day manual monitoring operation.

## Minutes from GDP meeting Friday 10th October

Commenced at: 11am Duration: 1hour

Those present : Louis Le Pen
Richard Drury

Items Discussed:

Assigning roles

Division of labour - Filling out group project review form (part 1).

How to tackle the work.

Actions Resulting and Any Reports Made:

Louis agreed to be secretary.

Richard agreed to be Treasurer.

It was decided that with a group of only 2 assignment of a chairman was not necessary.

It was agreed to share the workload without formally dividing up tasks, due to the small size of the group.

A new list of objectives was drawn up based on new information gathered and a Gantt chart was drawn up showing the broad order of works and anticipated duration's. These to be typed up in neat and handed in with the completed review form by Richard before the end of the day.

The team members agreed to dedicate each Thursday to working together on the project, this to be in addition to other actions that would be necessary throughout each week.

## Minutes from GDP meeting Monday 13th October

Commenced at: 10am Duration: 1hour

Those present : Louis Le Pen
Richard Drury
Dr Barton (Supervisor)

Items Discussed:

Information provided by NFDC which arrived on this day.

Outstanding actions from previous meetings which had largely been held up whilst waiting to see what the NFDC could provide.

Actions Resulting and Any Reports Made:

NFDC had provided us with an autocad map of the study area, therefore Louis agreed to try to find out if there was a copy of autocad that the team could use on the university campus.

Richard agreed to go through the information provided by the NFDC and catalogue everything that the group had.

Louis to continue searching for climatic data and conducting a search for useful literature on the subject of mole drains & also to investigate possible purchase of OS map.

Other outstanding actions are no longer relevant due to the re-ordering of work (see Gantt chart).

Richard and Louis to meet this Thursday for the first all day attack on the workload.

## Minutes from GDP meeting Monday 20th October

Commenced at: 10am Duration: 1hour

Those present : Louis Le Pen
Richard Drury
Dr Barton (Supervisor)

Items Discussed:

Appointment of 2nd examiner

Copies of Gantt chart and list of objectives to Dr Barton

Contacting Bartholomew

Reports on actions from last GDP meeting

Actions Resulting and Any Reports Made:

Dr Barton stated that he had someone in mind for the role of 2nd examiner and would contact them shortly.

Louis reported that he had faxed the Met office with a list of questions regarding climatic data for the study area, and had also approached some academics within the university. As yet no response has been received from either source.

Louis also reported that after discussions with Dr Clark (of the Civil and environmental engineering Dept), with regard to calculating a water balance equation for the study area, very detailed topographical and hydrogeological information would be required. Dr Clark recommended that a visual survey of the area would be the best way to gain a feel for it.

In connection with the topography of the area Louis had also investigated the possibility of obtaining an OS map. Reporting that with a number of options available, the most appropriate would be the purchase of a 1:10,000 scale map of the area (Cost £37). However nothing definite was decided on and investigations for the water balance components will continue.

Richard reported that he was still going through the information supplied by The NFDC, but already he had found gaps and inconsistencies in the data provided. The group therefore decided that it would be necessary to get back to the NFDC on this but not before a full review of the information by Richard has been completed. Ongoing action - Richard to catalogue data provided by the NFDC.

Having discovered that the Autocad map provided by the NFDC could be imported on and printed off using autosketch a hard copy had been printed on A1. The map showed the coastline along Barton-On-Sea where 3 of the 5 mole drain manholes are located. It was produced in 1993 and shows detailed contours of the coast as it was then.

With regard to contacting Bartholomew Richard stated that he would prefer to do this after the catalogue of the NFDC data had been completed.

It was decided to contact the NFDC after the catalogue had been complete in order to clarify what other, if any information they had and to check when there next monitoring of the mole drains would be due.

## Minutes from GDP meeting Mon 27th Oct

Commenced at: 10am Duration: 45mins

Those present : Louis Le Pen
Richard Drury
Dr Barton (Supervisor)

Items Discussed:

2nd examiner.

Alterations to Objectives list and Gantt chart.

Reports on ongoing work.

Meeting arranged with NFDC.

Research council money.

Formal review meetings.

Reports and any actions

Dr Barton stated that Dr Pitts had agreed to be second examiner.

Dr Barton suggested some improvements to the objectives list and Gantt chart, these were noted. Richard to make the alterations agreed upon.

Richard reported that he was continuing to catalogue the data supplied by NFDC, and Louis reported that a meeting had been arranged for Thurs 30th Oct to meet with the NFDC to discuss gaps in the data. Richard to fax NFDC with a list of queries prior to this meeting.

Dr Barton suggested that the research council might be persuaded to contribute money into research of mole drains, though this would not be part of the project, the idea only being to state a case for future study.

Louis reported still no response from the met office, and that he would continue to pursue climatic data. Also that he had taken out some BEng dissertations as part of the literature search and would try to assess if there was any relevant information contained within them.

Louis also reported that the NFDC next monitoring of the Mole drains had been put back a week and was now due to take place in the first week of November. As previously discussed, group members would attempt to accompany NFDC employees on this two day job.

## Minutes for GDP meeting with NFDC Thursday 30th October.

Commenced at: 10am Duration: 2hours

Those present : Louis Le Pen
Richard Drury
Andrew Bradbury (Engineer NFDC)

Items discussed:

List of queries on fax.

Next monitoring trip of Mole drains.

Reports and any actions

NFDC allowed the group access to their library regarding Cliff recession at Barton on sea. After looking through this information the group requested copies of several reports.

The copy of fax containing queries enclosed shows the basis of discussions for the meeting.

NFDC answered most queries, unfortunately it seems that a lot of data has been lost. Other unanswered queries were referred to absent colleagues, who will hopefully be able to enlighten the group when, and if, they can be contacted.

NFDC stated that the next monitoring trip would likely be on Tuesday the 4th November.

## Minutes from GDP meeting Monday 3rd November

Commenced at: 10am Duration: 1hour

Those present : Louis Le Pen
Richard Drury
Dr Barton (Supervisor)

Items Discussed:

Meeting with NFDC last Thursday

How to best continue with the project in the light of new information gained from the meeting with the NFDC.

Actions Resulting and Any Reports Made:

Dr Barton explained a method of calculating the Water Balance that he had come up with, however required data has still not been forthcoming despite a number of enquires.

Dr Barton suggested that the Mole drains could be modelled using a 2D soil seepage package, and that the group should contact Dr Cooper to discuss what computer packages are available.

The group explained to Dr Barton that some of the stated objectives were unobtainable because the information simply did not exist and that therefore, the groups approach to the project needed redefining, the group to consider how best to do this over the next week.

## Minutes from GDP meeting Monday 10th November

Commenced at: 10am Duration: 1hour

Those present : Louis Le Pen
Richard Drury
Dr Barton (Supervisor)

Items Discussed:

Monitoring trip with NFDC (4/11/97).

Problems with objectives.

Actions Resulting and Any Reports Made:

The group reported that the monitoring trip with the NFDC had been very useful, giving a valuable insight into the project and highlighting a number of problems, specifically with the monitoring system and also with several of the group objectives with respect to what would and would not be possible.

Given this new insight the group expressed concern that the data for the project was imperfect and that empirical modelling of the Mole drains as had previously been envisaged was impossible, this was due to not knowing exactly where the Mole drains were and not having enough monitoring readings.

Dr Barton said that this should not affect the validity of the project and that it was not necessary to produce a report that contained new understanding of the Mole Drains, provided that the report demonstrated that learning and thought had gone into its production.

The Group still to contact Dr Cooper who had unfortunately been out.

Louis reported that he had contacted Rendel and was awaiting a reply to a list of queries sent by fax. Unfortunately Bartholomew were unobtainable at the time of phoning.

Louis reported with respect to climatic data, that the Met Office still had not got back to him with the data requested and that university academics were still not responding to messages left for them.

## Minutes from GDP meeting Monday 17th November

Commenced at: 10am Duration: 1hour

Those present : Louis Le Pen
Richard Drury
Dr Barton (Supervisor)

Items Discussed:

Meeting with Dr Cooper

Redefined objectives

Actions Resulting and Any Reports Made:

The meeting with Dr Cooper gave the group to understand that the problem was too complex for current computer modelling software. In the light of this the group also met with Professor Powrie who suggested that a package called "slope" could be utilised to assess the before and after stability of the cliffs at Barton On Sea, and hence assess the effectiveness of the Mole drains without directly modelling them.

Dr Barton handed out a sheet redefining the group objectives taking into account new information gained since the start of the project. (See new objective sheet)

Louis again reported that climatic data had not been forthcoming.

No response from Rendel, the Met office or Nigel Arnell as yet.

It was decided that Richard would work on the slope idea and that Louis would continue to try and do a water balance calculation.

## Minutes from GDP meeting Monday 24th November

Commenced at: 10am Duration: 45mins

Those present : Louis Le Pen
Dr Barton (Supervisor)

Apologies: Richard Drury (due to illness)

Items Discussed:

Water balance calculation.

First formal review meeting.

Cliff recession rates.

Actions Resulting and Any Reports Made:

Louis reported that after finally making contact with Dr Arnell he had been able to obtain climatic data direct from the Everton met office weather station at only the cost of a journey to pick it up. This information being only in its raw form will require a lot of time consuming processing. Louis to continue work in this area.

First formal review meeting deferred until week eleven or twelve.

Dr Barton suggested that it would also be useful to try and calculate cliff recession rates, The NFDC to be contacted regarding this.

## Minutes from GDP meeting Monday 1st December

Commenced at: 10am Duration: 1hour

Those present : Louis Le Pen
Richard Drury
Dr Barton (Supervisor)

Items Discussed:

Photos from NFDC monitoring trip

Richard and Dr Barton discussed "slope" assumptions.

Progress.

Actions Resulting and Any Reports Made:

The group showed Dr Barton the photographs taken during the trip to monitor the mole drains. These visually show the difficulties in analysing the effect of the drains.

Team members continuing with their respective work for the project.

## Minutes from GDP meeting Monday 8th December

Commenced at: 10am Duration: 1hour

Those present : Louis Le Pen
Richard Drury
Dr Barton (Supervisor)

Items Discussed:

Formal review meeting.

Contacting Rendel and Bartholomew

"Slope"

Water Balance.

Actions Resulting and Any Reports Made:

Formal review meeting deferred until next term due to a lack of a convenient time for all parties to meet.

Louis reported that a fax had been sent to Rendel containing questions as discussed with Steve Fort (from Rendel) over the telephone, this had not been received by Rendel and had needed to be re faxed, as such no response has yet been received. Nigel Eglon from Bartholomew had again been unobtainable.

Team members continuing with their respective work for the project.

## Minutes from GDP meeting Monday 15th December

Commenced at: 10am Duration: 1hour

Those present : Louis Le Pen
Richard Drury
Dr Barton (Supervisor)

Items Discussed:

Progress.

Actions Resulting and Any Reports Made:

Richard and Dr Barton agreed on a meeting to discuss assumptions regarding slope.

Work continuing.

## Minutes from GDP meeting Monday 2nd February

Commenced at: 10am Duration: 1hour

Those present : Louis Le Pen
Richard Drury
Dr Barton (Supervisor)

Items Discussed:

Formal review meeting.

Reports on work completed over the Christmas vacation.

Actions Resulting and Any Reports Made:

Formal review meeting with 2nd examiner Dr Pitts arranged for 3pm 6th Feb in Dr Barton's office.

Brief overview of the project written by Louis to be passed on to Dr Pitts by Dr Barton Prior to Friday.

Rendel have responded to the letter and questions faxed to them prior to Christmas, providing the group with some useful information, a similar letter has been written and posted to Nigel Eglon of Bartholomew by Louis, which it is hoped he will respond to A.S.A.P.

Richard and Louis both progressing with their parts of the analysis, having spent some considerable time on their respective tasks over Christmas.

Actions to prepare for Friday and also continue with respective work.

It was also agreed to suspend weekly meetings until after the deadline for MDP projects had passed.

## AGENDA GDP FIRST FORMAL REVIEW MEETING
## 3PM FRIDAY 6TH FEBRUARY 98:

### HISTORY OF BARTON-ON-SEA:

1. Failure history.
2. Previous consultations.
3. Measures taken and Effectiveness.
4. Installation of Mole drains.

### INITIAL PROGRESSION/DIRECTION:

1. Site Investigation.
2. Investigation of data supplied by NFDC.
3. Research of further literature.

### REALISATION OF NEW PROJECT DIRECTION:

1. Problems with data supplied.
2. New set of objectives.

### WORK DONE - ANALYSIS OF DISCHARGE RATES

1. Water Balance study.
2. Slope stability.

### WORK INTENDED:

1. Overall Effectiveness of Mole Drains
2. Design of a monitoring system.
3. Recommendations.

## Minutes from GDP meeting Monday 9th March

Commenced at: 10am Duration: 1hour

Those present : Louis Le Pen
Dr Barton (Supervisor)

Apologies : Richard Drury (due to other engagement)

Items Discussed:

First Formal review meeting.

Progress.

Actions Resulting and Any Reports Made:

The group members felt that the review meeting had been satisfactory.

Louis reported that the water balance calculations had now progressed to the point of purchasing maps in order to estimate catchment areas. These maps were examined and how best to make these estimates was discussed.

Dr Barton agreed that he would try to contact Nigel Eglon of A.E. Bartholomew, since despite numerous messages left and one written request to provide information regarding the installation of the Mole Drains, there has been no response. It now seems likely that the project will not receive any input from Bartholomew.

Dr Barton confirmed that the minutes would form an appendix in the final report.

Louis reported that Richard was encountering difficulties with "Slope", due to code errors in the universities copy of the program. The package itself being commercially for sale at a prohibitive cost and with the universities copy having been obtained for free, it did not seem likely that the authors would provide support to remedy this. The calculation may therefore have to be made by hand.

## Minutes from GDP meeting Monday 16th March

Commenced at: 10am Duration: 1hour

Those present : Louis Le Pen
Richard Drury
Dr Barton (Supervisor)

Items Discussed:
Slope stability calcs.

Writeup.

Easter vacation availability of project members.

Date for final project presentation.

Actions Resulting and Any Reports Made:

Richard hand calculating the slope stability analysis.

Draft copy to be prepared for Dr Barton to read on the Friday at the end of the second week of the Easter vacation.

Group members and Dr Barton confirmed the dates that they would be available over Easter. (at least 3 weeks in all cases).

Several possible dates put forward for presentation exact date to be confirmed.

This to be the last formal meeting before the hand in, though group members and Dr Barton to liase frequently to agree how best to write up the project.