Advanced Environmental Hydrology System

Instruction Manual

S12-MKII

ISSUE 21

February 2014

Table of Contents

Disclaimer

This document and all the information contained within it is proprietary to Armfield Limited. This document must not be used for any purpose other than that for which it is supplied and its contents must not be reproduced, modified, adapted, published, translated or disclosed to any third party, in whole or in part, without the prior written permission of Armfield Limited.

Should you have any queries or comments, please contact the Armfield Customer Support helpdesk (Monday to Thursday: 0830 - 1730 and Friday: 0830 - 1300 UK time). Contact details are as follows:

United Kingdom	International
(0) 1425 478781 (calls charged at local rate)	+44 (0) 1425 478781 (international rates apply)
Email: support@armfield.co.uk	
Fax: +44 (0) 1425 470916	

Copyright and Trademarks

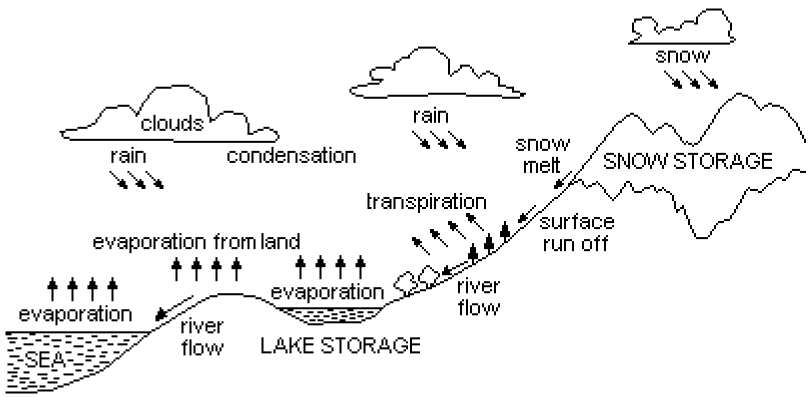
General Overview

This floor-standing unit is the only Hydrology System that includes features making it suitable for studying fluvial geomorphology. It combines the capabilities of the S10 Rainfall Hydrographs and S11 Ground Water Flow Unit into a single comprehensive facility. The system is fully instrumented for investigation of rainfall/run-off hydrographs, ground water abstraction studies and unique to this apparatus, fluvial mechanics.

This apparatus sets out to demonstrate, on a small scale, some of the physical processes found in hydrology. These processes fall into two related categories: the relationship between rainfall and run-off from catchment areas of varying permeability and the abstraction of ground water by wells, both with and without surface recharge from rainfall.

Thus it can be seen that it is concerned with that part of the hydrological cycle bounded by the arrival of "net rainfall" on the ground surface and catchment run-off either by surface streams or well abstraction.

The hydrological cycle describes the complete movement of water between the atmosphere, the land surfaces and the water masses of the earth. There are a number of possible routes that water can follow in moving round this cycle and these are outlined below.



Precipitation (rainfall) on the land surfaces is disposed of in various ways. What water remains after the ground has been wetted and evaporation and transpiration losses have been deducted, is termed the "net rainfall" and this may

i. soak into the ground (infiltrate) to join the ground water held in voids (normally very small)

ii. fill up surface depressions to form puddles, or

iii. any remaining will flow over the ground surface in the downhill direction to form streams and, subsequently, rivers.

Ground water also flows laterally under the influence of slopes, to reappear at the surface either to form springs or to increase stream flow by reverse infiltration through the bed.

Abstraction from wells is another way in which water can leave a catchment area and it can, therefore, be thought of as forming part of the run-off.

A proper understanding of these processes and their inter-relationships is essential for many purposes. Engineers are commonly concerned with the provision of water supplies for urban and irrigation needs; with the estimation of flood magnitudes and frequencies; with the consequences of land drainage works on flood risks, on the use of wells to de-water construction excavations and the drainage of lakes and polders.

Geologists and geographers are frequently faced with problems which involve hydrological processes such as drawing up a water balance for a catchment area, the investigation of morphological processes in rivers and streams, and the control of mud flows and soil erosion caused by surface and sub-surface water flows.

The range of experimental capabilities is significantly increased by the provision of a river inlet tank and outlet collecting tank. These enable a range of fluvial mechanics experiments to be carried out in related topics such as river flow and sediment transport, initiation and characteristics of bed-load motion, general and local scour in open channel flow etc.

Equipment Diagrams

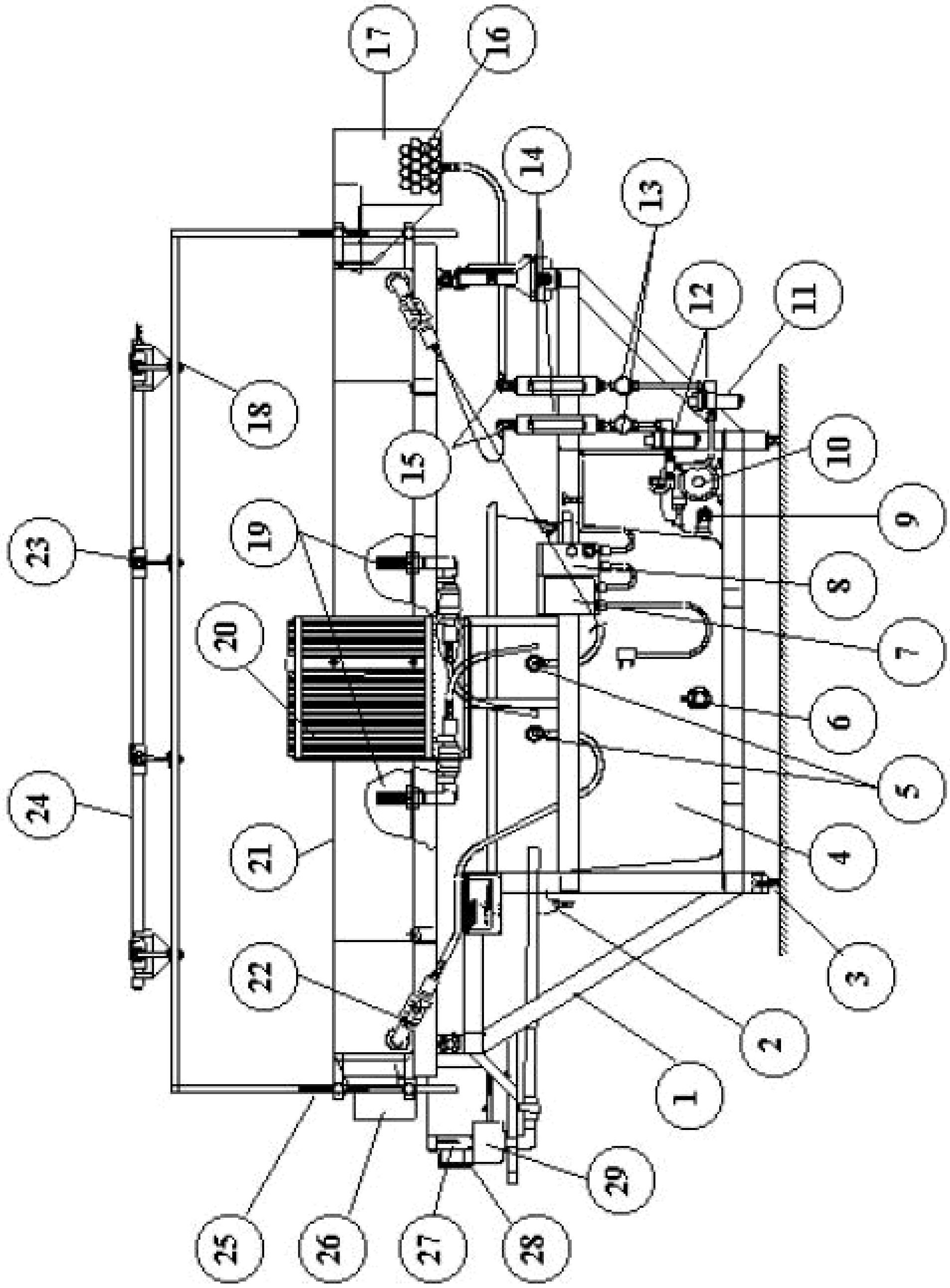


Figure 1: Front View of S12-MKII Hydrology System

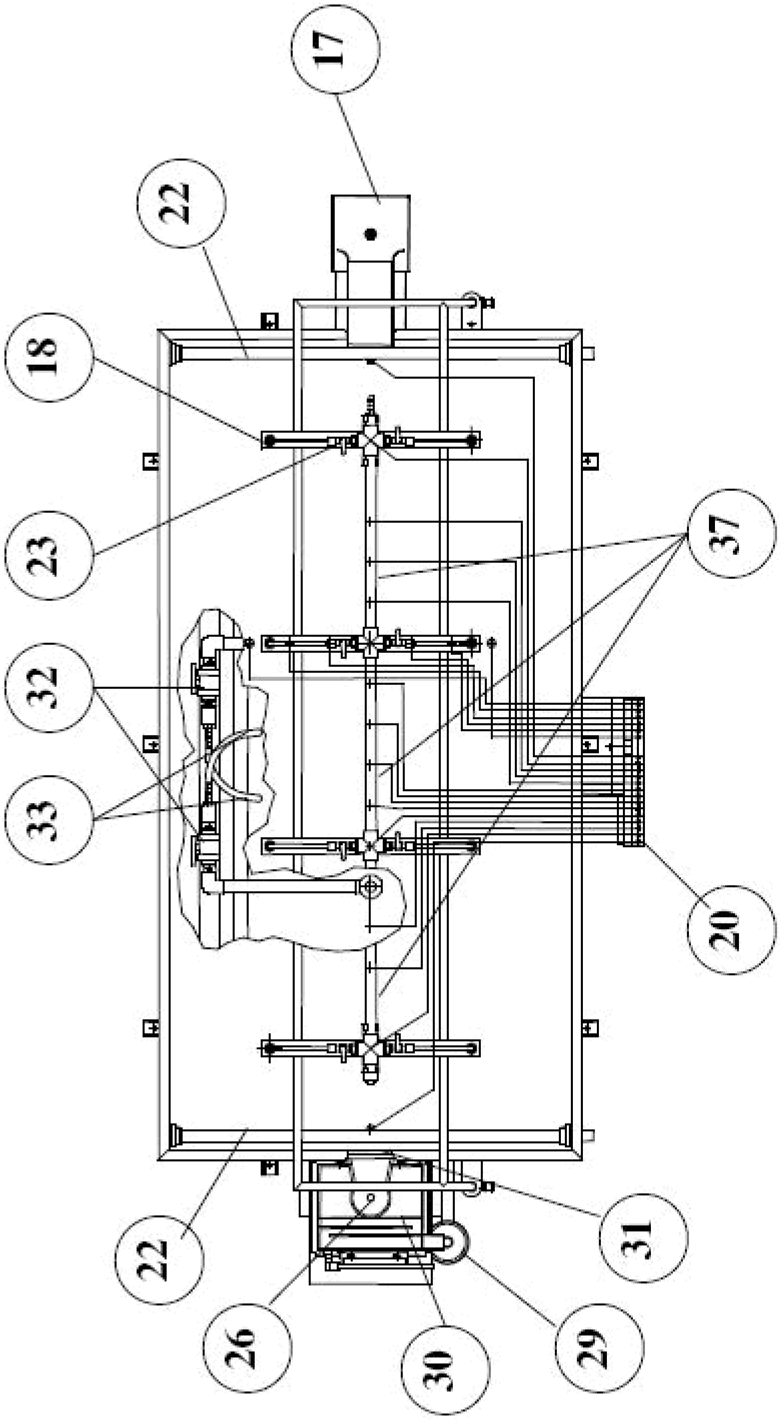


Figure 2: Plan View of S12-MKII Hydrology System

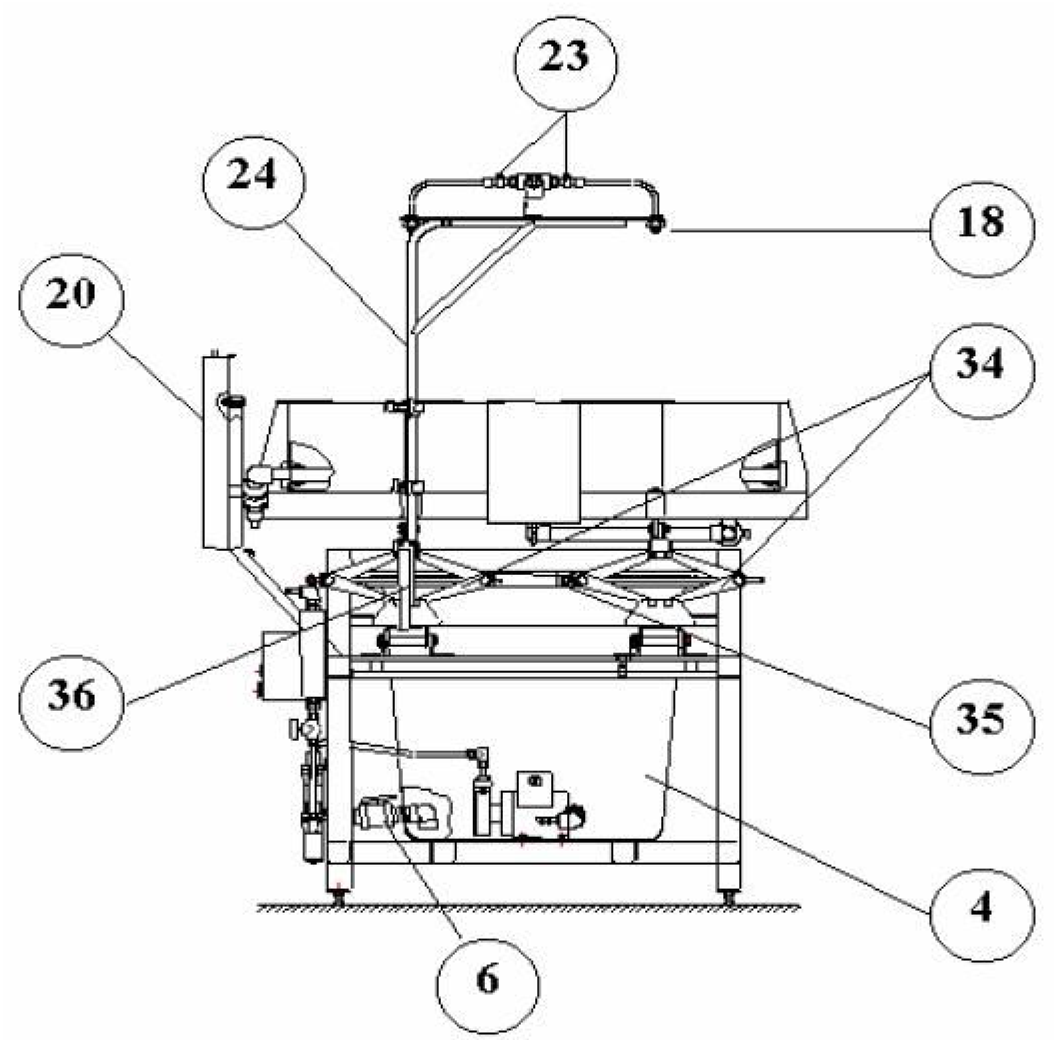


Figure 3: End View of S12-MKII Hydrology System

Important Safety Information

Introduction

All practical work areas and laboratories should be covered by local safety regulations **which must be followed at all times**.

It is the responsibility of the owner to ensure that all users are made aware of relevant local regulations, and that the apparatus is operated in accordance with those regulations. If requested then Armfield can supply a typical set of standard laboratory safety rules, but these are guidelines only and should be modified as required. Supervision of users should be provided whenever appropriate.

Your **S12-MKII Hydrology System** has been designed to be safe in use when installed, operated and maintained in accordance with the instructions in this manual. As with any piece of sophisticated equipment, dangers exist if the equipment is misused, mishandled or badly maintained.

Electrical Safety

There is a potential hazard of injury from electric shock due to mains electrical supply to water pump and Data Logging accessory when fitted (included on version S12-MKII-50).

To give increased operator protection, the unit incorporates a Residual Current Device (RCD), alternatively called an Earth Leakage Circuit Breaker, as an integral part of this equipment. If through misuse or accident the equipment becomes electrically dangerous, the RCD will switch off the electrical supply and reduce the severity of any electric shock received by an operator to a level which, under normal circumstances, will not cause injury to that person.

At least once each month, check that the RCD is operating correctly by pressing the TEST button. The circuit breaker **MUST** trip when the button is pressed. Failure to trip means that the operator is not protected and the equipment must be checked and repaired by a competent electrician before it is used.

Heavy Equipment

There is a potential hazard of injury from incorrect handing.

The equipment is heavy and must be handled properly when unpacking and positioning. Sand tank is heavy when filled with sand or water and care must be exercised when using the jacking system.

Water Borne Hazards

The equipment described in this instruction manual involves the use of water, which under certain conditions can create a health hazard due to infection by harmful micro-organisms.

For example, the microscopic bacterium called Legionella pneumophila will feed on any scale, rust, algae or sludge in water and will breed rapidly if the temperature of water is between 20 and 45°C. Any water containing this bacterium which is sprayed or splashed creating air-borne droplets can produce a form of pneumonia called Legionnaires Disease which is potentially fatal.

Legionella is not the only harmful micro-organism which can infect water, but it serves as a useful example of the need for cleanliness.

Under the COSHH regulations, the following precautions must be observed:

- Any water contained within the product must not be allowed to stagnate, ie. the water must be changed regularly.
- Any rust, sludge, scale or algae on which micro-organisms can feed must be removed regularly, i.e. the equipment must be cleaned regularly.
- Where practicable the water should be maintained at a temperature below 20°C. If this is not practicable then the water should be disinfected if it is safe and appropriate to do so. Note that other hazards may exist in the handling of biocides used to disinfect the water.
- A scheme should be prepared for preventing or controlling the risk incorporating all of the actions listed above.

Further details on preventing infection are contained in the publication “The Control of Legionellosis including Legionnaires Disease” - Health and Safety Series booklet HS (G) 70.

Note: Water will stagnate if left in any of the tanks. Water must be changed at regular intervals. Overhead spray system and sand in the tank must be flushed at regular intervals to exclude micro-organisms.

The COSHH Regulations

The Control of Substances Hazardous to Health Regulations (1988)

The COSHH regulations impose a duty on employers to protect employees and others from substances used at work, which may be hazardous to health. The regulations require you to make an assessment of all operations, which are liable to expose any person to hazardous solids, liquids, dusts, vapours, gases or micro-organisms. You are also required to introduce suitable procedures for handling these substances and keep appropriate records.

Since the equipment supplied by Armfield Limited may involve the use of substances which can be hazardous (for example, cleaning fluids used for maintenance or chemicals used for particular demonstrations) it is essential that the laboratory supervisor or some other person in authority is responsible for implementing the COSHH regulations.

Parts of the above regulations are to ensure that the relevant Health and Safety Data Sheets are available for all hazardous substances used in the laboratory. Any person using a hazardous substance must be informed of the following:

- Physical data about the substance.
- Any hazard from fire or explosion.
- Any hazard to health.
- Appropriate First Aid treatment.
- Any hazard from reaction with other substances.
- How to clean/dispose of spillage.

- Appropriate protective measures.
- Appropriate storage and handling.

Although these regulations may not be applicable in your country, it is strongly recommended that a similar approach be adopted for the protection of the students operating the equipment. Local regulations must also be considered.

Description

Where necessary, refer to the drawings in the Equipment Diagrams section.

Overview

The equipment consists of a sand tank (21) that is mounted on a support frame (1) with the necessary services, features and instrumentation to facilitate studies of ground water flow, ground water abstraction, flood hydrographs and fluvial mechanics.

Frame

The frame incorporates an adjustable foot (3) on each leg to allow the equipment to be levelled. It is suggested that the top edge of the sand tank (21) be used as the datum when levelling the equipment.

The frame incorporates a pair of scissor type jacks (34) at one end that allow the sand tank to be elevated. The jacks are linked so that the sand tank remains stable when raising or lowering. An indicator (36) shows the gradient of the sand tank. The jacking handle is simply inserted into the coupling (35) on the front jack and rotated clockwise to raise the sand tank or anticlockwise to lower the sand tank. The jacking handle should be removed after adjusting the elevation of the sand tank.

CAUTION: Although the sand tank cannot move suddenly when adjusting the elevation, extreme care should be taken when operating the jacks to prevent crushing of fingers, hands or other objects between the upper and lower frames.

Water Feeds

A sump tank (4) and centrifugal pump (10) mounted in the frame, beneath the sand tank, provide the water for the various demonstrations. Water exiting the sand tank from the various outlets returns to the sump tank under gravity for reuse. An overflow pipe (2) on the side of the side of the sump tank ensures that the tank cannot be overfilled. A drain valve (6) is connected to a tapping at the base of the sump tank. The centrifugal pump draws water from the sump tank via a tapping (9) at the base of the tank. Water from the pump passes through two parallel feed arrangements, each incorporating a filter (12), pressure regulator (11), feed flow control valve (13) and variable area flowmeter (14). The pressure regulator in each feed ensures that the flow is not affected by changes in the other feed provided that the regulator is adjusted to suit. The outlet from each feed is terminated with a self-sealing quick-release connector (15) that allows water to be fed to either end of the sand tank, the spray nozzles or the river inlet tank as required via the appropriate flexible connection. The self-sealing quick-release connectors allow rapid changes to the configuration without the need for tools.

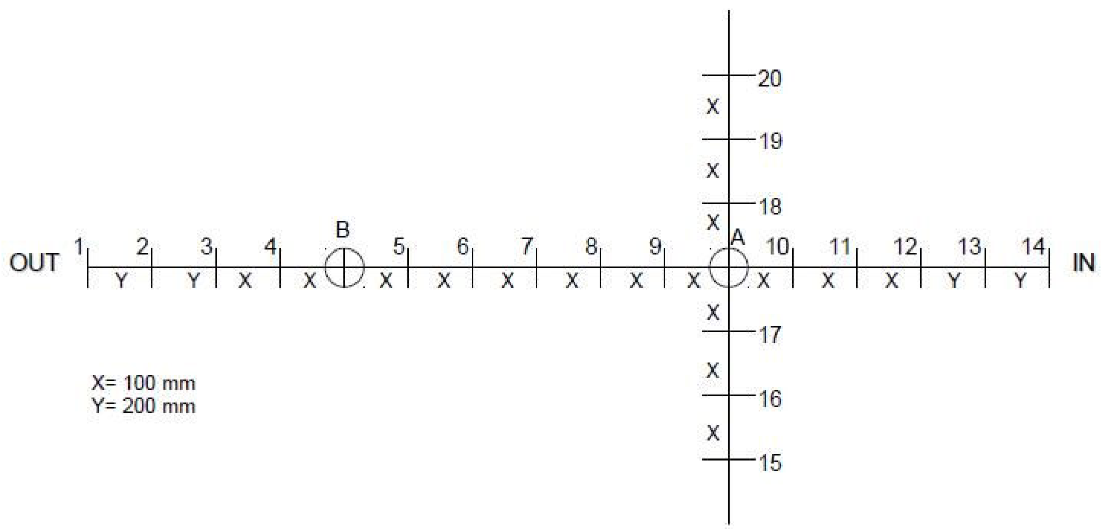
The outlet from the centrifugal pump incorporates a pressure relief valve to limit the system pressure to a maximum of approximately 3.0 barg and prevent the pump from overheating if the flow from the two outlets is restricted or stopped. Water discharging from the relief valve is returned to the sump tank via a connection in the side wall of the tank. When demand from the two outlets is high, the relief valve will remain closed to maintain the pressure in the system. When demand is reduced and the system pressure rises above 3.0 barg, the valve will open to relieve the excess flow. The relief pressure is adjustable and set prior to delivery but instructions are included in the Routine Maintenance section of this manual should further adjustment be necessary.

The electrical control box is mounted on the frame below the sand tank and incorporates a starter (7) for the pump and an RCD (8) to protect the operator against electrical shock.

Sand Tank

The shallow sand tank (21) is fabricated from stainless steel for corrosion resistance and should be filled with sand (not supplied by Armfield) or other granular material as appropriate to the studies (refer to page 15 for details on choosing a suitable granular material). An array of tapping points (37) in the sand tank floor is connected to a multi-tube manometer (20) that enables the water table surface (phreatic surface) to be determined. The level in each tube can be read by sliding the common scale along the track at the top of the manometer. Before using the manometer to measure water levels it is important to expel air from the flexible tubes connecting the manometer tubes to the tapping points. (Refer to the Commissioning section). Each tapping (37) in the sand tank floor incorporates a filter mesh to retain the sand while allowing the water to flow. Two cylindrical wells (19) are also included in the sand tank floor. The wells are covered with stainless steel mesh to prevent the loss of sand. Valves and pipework beneath the sand tank allow the water draining from each well to return to the sump tank. In-line feed flow control valves (32) allow the flow to be varied. Flexible outlet hoses (33) allow the water to be diverted to a collecting vessel (not supplied) for the purpose of measuring the volumetric flowrate. The two wells are purposely designed to be short in length so that they can be left in position without affecting the surface flow experiments. The plug of sand directly above each well can be removed if required for abstraction experiments but the affect on the results will be negligible if the sand is left in place.

The reference number/spacing of the tappings (37) and the position of the wells (19) is shown below:



Location of tappings and wells in the sand tank

A perforated pipe (22), in the form of a French drain, is buried in the sand at each end of the sand tank. These allow water to be drained from the sand tank or admitted to the sand tank as required. Each French drain is connected through the side wall of the sand tank to a flexible tube terminated with a self-sealing quick-release connector. When it is required to drain water from the sand tank the flexible tube is connected to one of the quick-release connectors (5) on the side of the sump tank, allowing the water to return to the sump tank. The flow of water can be varied using the in-line valves (32). When it is required to admit water to the sand tank the flexible tube is connected to one of the water feeds via the quick-release connector (15).

A deep cut-out (31) at the left-hand end of the sand tank allows water (and transported sediment) to leave the sand tank. This cut-out incorporates side slots that locate stop-logs (rectangular strips of plastic) that create a rectangular weir. Adding or subtracting stop-logs of different sizes can vary the height of the weir. A weir chute/diffuser (26), fabricated from clear acrylic, is bolted to the end wall of the sand tank adjacent to the cut-out. The weir chute/diffuser allows the water and sand exiting the sand tank to fall into the outlet collecting tank (28) with minimal disturbance to the surface of the water or any collected sediment in the outlet collecting tank (described below). A clear polythene skirt with slits is attached to the bottom of the weir chute/diffuser, using a rubber band, to minimise splashing as the water and sand fall into the collecting tank.

Outlet Collecting Tank

Water and sediment exiting the sand tank via the weir chute/diffuser is deposited into the outlet collecting tank (28) that is designed to measure the flow of water and collect any sediment washed from the sand tank. This tank is fabricated from clear acrylic and incorporates the following features:

The water and sediment fall into the open area of the tank. A vertical mesh screen (30), supported by perforated plates on either side, ensures that sediment is retained in the tank. The water flows through the mesh, along a stilling channel then over a narrow rectangular notch (31) before discharging into a funnel (29) that returns the water to the sump tank for re-use. The flowrate of the water is determined from the height of the water upstream of the notch using an inclined manometer that incorporates a scale calibrated directly in litres/min. The manometer is mounted directly on the side of the outlet collecting tank.

Sediment falling into the tank is deposited in the bottom of the tank. The sand can be removed by lifting the tank clear from its support. If it is required to collect the sand for quantitative measurements then a piece of fine cloth or a small strainer can be positioned beneath the weir chute/diffuser to collect the sediment. If this is changed at regular intervals then the rate of accumulation of the sediment can be determined.

When version S12-MKII-50 has been supplied, additional instrumentation and a USB interface is included that can be used to measure both the water flow and the accumulation of sediment continuously using a PC.

S12-MKII-50 (S12-MKII Including Data Logging and Educational Software)

Note: This option can only be supplied at the time of ordering the equipment and cannot be fitted to en existing S12-MKII.

This system works by measuring the height of the water and the combined weight of the sand and water collected in the outlet tank (28). The water flow rate is calculated from the height over the outlet weir (27) and the sediment flow rate is calculated from the rate of change of the weight. The system comes with educational software incorporating help texts, graph plotting, etc. and requires a user provided PC with an available USB port. Refer to the sections Installing the Software and Operating the Software for further information. Alternatively, refer to the Help text in the software.

The electronics associated with the load cell and pressure sensor are installed in an enclosure that is mounted underneath the support for the Outlet Collecting Tank. The load cell is located underneath the Outlet Collecting Tank and the pressure sensor is connected to a tapping adjacent to the inclined manometer on the side of the Outlet Collecting Tank. The lead from the pressure sensor can be disconnected from the front of the electrical enclosure when it is required to remove the tank for emptying / cleaning. After refilling the tank with water to the base of the weir it will be necessary to re-prime the connection to the pressure sensor to eliminate any air bubbles.

Overhead Spray Nozzles

Rainfall onto the catchment area is provided by two rows of four spray nozzles (18) above the tank, mounted on a support frame (24). The height of the spray nozzles above the sand tank can be varied to optimise the demonstration by adjusting the height of the support frame. This is achieved by withdrawing the spring-loaded plunger (25) at each end, raising or lowering the support frame to the required height, then re-locating the spring loaded plunger in the appropriate hole. One person at each end of the equipment should hold the support frame while performing the adjustment.

An isolating valve (19) upstream of each nozzle allows the pattern to be changed as required. Since the flowrate through each nozzle is dependent on the pressure, if the appropriate pressure regulator (12) is adjusted to give the required flowrate then the flow through each nozzle will remain constant when other nozzles are turned on or off. To achieve this the feed flow control valve (13) should be opened fully and the pressure regulator adjusted to give the required flow through the nozzles.

The flexible tube from the arrangement of spray nozzles is connected to one of the water feeds, when required, using the self-sealing quick release connector (15). The height of the nozzles should be adjusted at the required flowrate to give adequate coverage over the surface of the sand without excessive spray over the sides of the sand tank as described above.

River Inlet Tank

A river inlet tank (17) mounted at the right-hand end of the sand tank allows a stream of water to flow onto the surface of the sand, simulating the flow from a river upstream. The river inlet tank is fabricated from stainless steel and is bolted to the end wall of the sand tank adjacent to the shallow cut-out. Water enters at the base of the tank, flows upwards through a bed of glass marbles (16) to minimise any turbulence then flows sideways onto the surface of the sand through a rectangular section.

An anti-erosion mat (small section of mesh) is supplied to reduce any local scour where the water enters the sand tank. This mat is buried just beneath the surface of the sand adjacent to the outlet of the river inlet tank.

The flexible tube from the base of the sand tank is connected to one of the water feeds, when required, using the self-sealing quick release connector (15).

Choice of Granular Material for the Sand Tank

It has been found through experimentation that well-graded silica sand in the range 16/30 mesh (1000 micron to 500 micron) will allow all of the experiments described in the teaching manual to be carried out without the need to change the sand between runs. To minimise the cost of filling the tank it is suggested that 16/30 mesh swimming pool silica filter grit be used. 550 kg of sand will be required to fill the tank.

Obviously the size and grading of the sand used in the catchment tank can be varied to meet the particular needs of the experimenter. Fine sand will normally give a lower coefficient of permeability and hence slower run-off and steeper water table slopes than a coarse one.

Before loading any sand into the sand tank it is most important that the sand should be first thoroughly washed to remove all silt and salts present. After filling with sand it is suggested that the water is circulated via the French drains for a period of approximately one hour then drained from the sump tank and re-filled with clean water (See Commissioning section).

Note: It is important that the granular material used in the sand tank is free from fine sediment as this will gradually block the filter material used on the French drains, the two wells, the tappings to the manometer tubes and the filters in the pressure regulators. The use of sand taken directly from a beach or quarry is not recommended. If this is necessary then the sand must be given multiple washes with intermediate drying on trays to eliminate the soluble salts etc. The sand should also be graded using sieves to remove those fractions smaller than 500 microns and larger than 1000 microns.

Accessories

The S12-MkII is supplied complete with the following accessories:

Tank Sealing Plate: Sometimes it is required to seal the end of the sand tank (e.g. for groundwater flow demonstrations where leakage through the stop-log weir is unacceptable). When this is the case, the rectangular plate supplied should be bolted over the cut-out (31) in place of the weir chute/diffuser (26).

Scraper: When the sand tank has been filled with sand, the surface profile for the various experiments can be formed using the scraper. One edge has square corners to create sharp features and the other edge has rounded corners to prevent digging-in or create softer features.

Sand Scoop: Having created the general surface profile using the scraper, any local features or channels can be created using the small plastic scoop.

Anti-erosion Mat: This small section of mesh is buried just beneath the surface of the sand adjacent to the outlet of the river inlet tank to reduce any local scour where the water enters the sand tank.

S12-MODELS (Optional accessory): The range of experiments using this equipment is endless and specific models can be fabricated by the user as required. However, a set of basic models is available as on option to facilitate the various experiments listed in the teaching manual. Refer to the Laboratory Teaching Exercises for details on using the models. The following models are supplied with the S12-MODELS option:

a. Fabricated trays and rings:

   Circular open ended ring, 500mm diameter x 60mm high

   Small square open ended ring, 300mm x 300mm x 60mm high

   Closed ring with removable central clear plastic standpipe, 500mm diameter x 60mm high

   Large rectangular open ended ring, 1000mm x 500mm x 60mm high

   Large rectangular closed ring with hole, 1000mm x 500mm x 60mm

b. Impermeable catchment:

   1000 gauge Polythene sheet, sufficient to cover the catchment area.

c. Permeable catchment:

   Sheets of absorbent material: sufficient to cover the catchment area.

d. Model structures machined from solid PVC:

   Cylinder - 25mm diameter

   Rectangular bridge pier - 25mm wide, 75mm long, 125mm high

   Rounded bridge pier - As above but with semicircular ends

   Streamlined bridge pier - As above but with ends chamfered (60° inc.)

Installation

Advisory

Before operating the equipment, it must be unpacked, assembled and installed as described in the steps that follow. Safe use of the equipment depends on following the correct installation procedure.

Where necessary, refer to the drawings in the Equipment Diagrams section.

Electrical Supply

S12-MKII-A or S12-MKII-50-A

The equipment requires connection to a single phase, fused electrical supply. The standard electrical supply for this equipment is 230V, 50Hz. Check that the voltage and frequency of the electrical supply agree with the label attached to the supply cable on the equipment.

The equipment is supplied with an appropriate plug fitted so it will not be necessary for an electrician to terminate any bare electrical connections when installing the equipment. For information the supply cable and electrical wiring use the following convention:

GREEN/YELLOW	-	EARTH
BROWN	-	LIVE (HOT)
BLUE	-	NEUTRAL
Supply fuse rating	-	5 AMP

S12-MKII-B or S12-MKII-50-B

The equipment requires connection to a single phase, fused electrical supply. The standard electrical supply for this equipment is 120V, 60Hz. Check that the voltage and frequency of the electrical supply agree with the label attached to the supply cable on the equipment.

Versions S12-MKII-B and S12-MKII-50-B are supplied with a loose transformer to step-up the 120V supply to 230V to suit the equipment. The transformer should be sited adjacent to the 120V mains outlet socket in the laboratory, in a dry location. The mains lead from the S12-MKII or S12-MKII-50 is simply plugged into the 230V outlet socket on the front of the transformer.

The equipment is supplied with appropriate plugs fitted so it will not be necessary for an electrician to terminate any bare electrical connections when installing the equipment. For information the supply cable and electrical wiring use the following convention:

GREEN/YELLOW	-	EARTH
BROWN	-	LIVE (HOT)
BLUE	-	NEUTRAL
Supply fuse rating	-	10 AMP

S12-MKII-G or S12-MKII-50-G

The equipment requires connection to a single phase, fused electrical supply. The standard electrical supply for this equipment is 230V, 60Hz. Check that the voltage and frequency of the electrical supply agree with the label attached to the supply cable on the equipment.

The equipment is supplied with an appropriate plug fitted so it will not be necessary for an electrician to terminate any bare electrical connections when installing the equipment. For information the supply cable and electrical wiring use the following convention:

GREEN/YELLOW	-	EARTH
BROWN	-	LIVE (HOT)
BLUE	-	NEUTRAL
Supply fuse rating	-	5 AMP

Cold Water Supply

The sump tank must be filled with clean cold water before use or after draining for maintenance. It is not necessary to provide a permanent connection to the cold water supply.

Laboratory Drain

A drain will be required at floor level for draining the system during maintenance using the drain valve (6) at the base of the sump tank. It is not necessary to provide a permanent connection from the drain valve (6) to the drain.

The overflow connection (2) on the side of the sump tank should be permanently connected to a floor level drain to ensure that the sump tank does not over fill during operation.

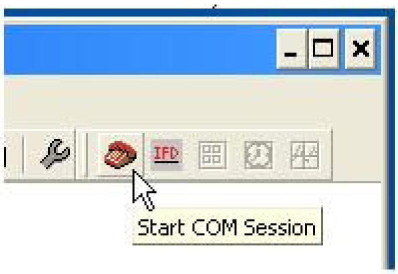
Installing the PC Software (Version S12-MKII-50 only)

If it is required to operate S12-MKII using the optional software supplied with S12-MKII-50 then it will be necessary to install the software from the CD-ROM supplied with S12-MKII-50 onto an appropriate PC (PC not supplied).

For instructions on how to install and run the software insert the CD-ROM into the optical drive on the PC (PC not supplied) then choose 'Help' from the menu.

After installing and running the software on the PC, instructions on how to operate the software can be obtained by choosing the 'Help' tab in the top right hand corner of the screen as shown below:

Note that when operating the software for the first time it will be necessary to enable the USB virtual COM port by choosing the Red telephone icon (Start COM session).



Full instructions about enabling the port are included in the Help menus.

Installing the Equipment

The equipment is supplied with the majority of the components already assembled. Final assembly should be completed as follows.

1. Ensure that all packaging materials any other debris has been removed from the equipment.

2. Situate the Frame (1) in the required location.

3. Adjust the height of the spray nozzles to position the tip of the nozzles approximately 350 mm above the top rim of the sand tank. The nozzle support frame (24) can be moved by withdraw the spring-loaded plunger (25) at each end. One person at each end of the equipment should hold the nozzle support frame while performing the adjustment. Re-insert the spring-loaded plunger in the appropriate hole at each end ensuring that the nozzle support frame remains parallel with the top edge of the sand tank.

4. Attach the level indicator (36) to the frame using the two fixings supplied.

5. Adjust the inclination of the sand tank to zero, shown by the level indicator (36), using the scissor jacks (34) at the right hand end of the frame. The jacks are operated by inserting the loose jack handle into the coupling (35). The jack handle should be removed after adjusting the level of the sand tank.

   Level the Frame by means of the four adjustable feet (3) located at each of the framework legs. Use a spirit level (not supplied) on the top edge of the sand tank (21) to determine the level and adjust the feet to level the sand tank in both planes.

6. Ensure that the vertical mesh screen (30), sandwiched between two perforated plates, is located in its support groove inside the outlet collecting tank (28). Place the white plastic tank support in the recess at the end of the frame with the tank locating pegs pointing upwards - below the weir chute/diffuser (26). Locate the outlet collecting tank on the support ensuring that it is positioned within the locating pegs.

   If assembling the S12-MKII-50 then it will be necessary to connect the lead from the pressure sensor on the side of the collecting tank to the connector on the front of the electrical enclosure. Before use it will be necessary to prime the tapping to the pressure sensor with water to ensure accurate measurements. This procedure is described in the Commissioning section.

The load cell is permanently fitted underneath the outlet collecting tank and the lead is already connected to the electronics enclosure.

7. Place the various models and accessories in a cupboard or similar place to avoid damage or loss.

Commissioning

The following procedure is presented as a series of steps to check that the equipment is functioning correctly following installation. The procedure should be completed before filling the sand tank with granular material.

1. Ensure that the sump tank (4) and sand tank (21) are clear of packaging materials then wipe the surfaces with a soft damp cloth to remove any transit film.

2. Wash the loose glass marbles (16) in a bucket of warm soapy water. Fill the river inlet tank (17) with clean water then carefully place the marbles in the base of the river inlet tank (the water will cushion the fall). Place the plastic stop-logs in the deep slot (31) at the end of the sand tank to allow the sand tank to retain water up to approximately half height.

3. Ensure that the overflow on the sump tank is connected to a suitable floor drain using flexible tubing (not supplied). Ensure that the drain valve (6) at the base of the sump tank is closed then fill the sump tank with clean water to approximately half height.

4. Connect the flexible tube from both French drains (22) to the feed quick release connectors (15) above both flowmeters. Make sure that the in-line valve on both French drains is fully open. Open both feed flow control valves (13) below the flowmeters then adjust both pressure regulators (12) to give maximum flow (pull the knob then turn the knob fully clockwise).

5. Connect the electrical supply to the equipment and check the operation of the RCD (7) by pressing the test button. The RCD must trip when the button is pressed. If the RCD does not trip or it trips before pressing the test button then it must be checked by a competent electrician before the equipment is used.

6. Ensure that the sump tank contains water then switch on the pump (10) by pressing the 'on' button on the motor starter (8) and check that water is delivered to the sand tank via the French drains (22).

7. When the pump has fully primed adjust both pressure regulators to give a reading of 3.0 litres/min on each flow meter with the flow control valve (13) fully open. Observe that the flow into the sand tank is steady on both flowmeters. Check the sand tank and pipework for leaks.

8. Switch off the pump then close the flow control valves (13) below both flow meters. Disconnect the French drains from the feed outlets by pressing the release button on each connector.

9. Check that water is returned to the sump tank via the relief valve at the pump outlet. The pressure gauge on each regulator should show approximately 3.2 barg. If water does not return to the sump tank or the pressures indicated are too high or too low then switch off the water pump and refer to the Routine Maintenance section of this manual.

10. Ensure that the isolating valve (23) upstream of each spray nozzle is fully open. Connect the flexible tube from the overhead sprinklers to the quick release connector (15) on the feed outlet above the 3 l/min flowmeter. Open the appropriate feed flow control valve (13) fully then switch on the pump. Adjust the corresponding pressure regulator (12) to give a reading of 2.5 litres/min on the corresponding flow meter (14). (To change the setting of the pressure regulator, pull the grey knob upwards then rotate the knob clockwise to increase the flow, anticlockwise to decrease the flow). Observe that water is delivered smoothly to the spray nozzles after initial priming/purging of the air. Check that the sprinkler system is leak tight. Leave the spray nozzles operating.

11. Connect the flexible tube from the base of the river inlet tank (17) to the quick release connector (15) on the other feed outlet. Open the appropriate feed flow control valve (13) fully then adjust the corresponding pressure regulator (11) to give a reading of 5.0 litres/min on the flow meter (14). Observe that water fills the river inlet tank then flows into the sand tank via the channel section. Check that the river inlet system is leak tight. Leave water flowing into the sand tank.

12. With water in the sand tank open the well control valves (32) fully and check that water is returned to the sump tank - the flexible tubing (32) must divert water back to the sump tank. Check the system for leaks.

13. Close both well flow control valves (32) and allow the water level in the sand tank to increase until level with the top of the stop-logs - approximately half full. Switch off the pump and close the feed flow control valves.

14. Place a single drop of wetting agent in each manometer tube (20) to minimise the effect of surface tension. Fill the outer tubes with clean water until approximately half full. These two tubes are connected and form a U tube that can be used for levelling the manometer. Unclamp the manometer and adjust the position until the level is the same in both tubes – using the moving scale to measure the height.

15. Disconnect the flexible tube from the base of each manometer tube in turn (except the outer pair) and allow water to flow into a suitable receptacle until all air is expelled from the tubing between the tapping (37) in the bed of the sand tank and the free end of the tube. When correctly primed the level in each manometer tube should be the same corresponding to the free surface of the water inside the sand tank. Any tube indicating a higher or lower level should be re-primed.

16. Ensure that the outlet collecting tank (28) is clean and in position beneath the weir chute/diffuser at the end of the sand tank. Ensure that the clear polythene skirt with slits is attached to the bottom of the weir chute/diffuser using an elastic band. This prevents splashing when water and sand fall into the collecting tank. Place a drop of wetting agent inside the inclined manometer tube on the side of the tank. Open the flow control valve (13) to the river inlet. Start the pump then adjust the pressure regulator to give a flow of 3.0 litres/min into the sand tank. Allow water to flow over the stop-logs, into the weir chute/diffuser (26) and into the outlet collecting tank (28). When the outlet collecting tank has filled observe that the water flows over the rectangular notch (27) then flows to the sump tank via the collecting funnel

(29). Observe that the flow of water is indicated on the calibrated scale adjacent to the inclined tube. Check the system for leaks.

17. Switch off the water pump, close all valves and open the well flow control valves (32) to drain the sand tank (ensure that the ends of the flexible tubing are located inside the sump tank. The equipment is now ready to be filled with sand for experimental purposes. Refer to Choice of Granular Material for the Sand Tank for suggestions on suitable granular material for filling the sand tank.

18. If the S12-MKII-50 version has been supplied then the following additional actions will be necessary to ensure accurate measurement of water level inside the collecting tank:

    A plastic syringe with catheter attached is supplied for priming the connection to the pressure sensor on the side of the collecting tank that is used to measure the water level. Fill the plastic syringe with water then insert the catheter through the tapping. Gradually inject water into the tapping and withdraw the catheter until the tapping is completely filled with no air bubbles present. It will be necessary to repeat this procedure after removing the tank for emptying/cleaning etc.

    When operating the equipment using the software ensure the level sensor is zeroed in the software when the water level is coincident with the bottom of the notch in the outlet weir.

Electrical Wiring Diagram

Click on the relevant link to invoke the Wiring Diagram:

S12-MKII Electrical wiring diagram CBM28622D

S12-MKII-50 Sensor wiring diagram ACM33737D

Printed Versions of this Instruction Manual
Please note, all wiring diagrams are appended at the rear of this manual. If viewing this Instruction Manual via Help Text in Armfield Software refer to the printed version of the manual for these diagrams.

Operation

Operating the PC Software

Details about operating the optional software can be obtained by choosing the 'Help' tab in the top right hand corner of the screen as shown below:

Installing and using the S12-MKII-50 Data Logger

Function of the Data logger and software

When supplied, the S12-MKII data logger is located underneath the collecting tank at discharge end of the sand tank. The data logger incorporates a USB connector at one end for powering the water level and weight sensors and logging the measured data via a PC.

A flexible tube connected from a pressure sensor inside the data logger, is connected to the collecting tank via a Guest quick release connector to measure the water level inside the collecting tank.

Installing the PC Software

Before operating S12-MKII-50 it will be necessary to install the software from the CD-ROM supplied with S12-MKII-50 onto an appropriate PC (PC not supplied).

For instructions on how to install and run the software insert the CD-ROM into the optical drive on the PC (PC not supplied) then choose 'Help' from the menu.

After installing and running the software on the PC, instructions on how to operate the software can be obtained by choosing the 'Help' tab in the top right hand corner of the screen as shown below:

Note that when operating the software for the first time it will be necessary to enable the USB virtual COM port by choosing the Red telephone icon (Start COM session).

Full instructions about enabling the port are included in the Help menus.

Connecting the S12-MKII-50 Data Logger

The data logger incorporates a USB connector at one end for powering the water level and weight sensors and logging the measured data via a PC. The USB lead supplied should be connected from the socket on the data logger to the USB port on a suitable computer running the Armfield S12-MKII-50 Software. The basic operation of the S12-MKII-50 can be confirmed by referring to the Operating the PC Software section.

Operating the PC Software

Details about operating the software can be obtained by choosing the 'Help' tab in the top right hand corner of the screen as shown below:

The software is split into three parts to suit the different exercises associated with S12-MKII.

Part 1 of the software is used to determine the Sand Factor (voidage) of the sand used in the sand tank.

Part 2 of the software is used for continuous logging of the Outflow from the collecting tank and any change in mass, allowing rainfall hydrographs, sediment yield etc to be monitored continuously throughout an exercise. The software also allows all relevant settings to be manually entered for future reference.

By choosing Rainfall in Experiment type, data relating to Mass change is not recorded allowing Height and Flowrate only to be recorded. Choosing Sediment Transport in Experiment type allows Mass of Sand and Sediment Yield to be recorded in addition to the Height and Flowrate.

Part 3 of the software is used for manual entry of results obtained from the bank of manometer tubes allowing water table profiles, draw-down at wells etc to be recorded and graphically presented. The software also allows all relevant settings to be manually entered for future reference.

Note that when using Part 2: Continuous Logging it will be necessary to zero the level sensor in the collecting tank and to enter the initial mass of the collecting tank when filled with water to obtain accurate results. These operations should be carried out as follows:

Zeroing the Height Over Weir reading

At the start of an exercise it will be necessary to zero the reading for Height Over Weir so that Out Flow Rate is correctly calculated. To zero the reading fill the collecting tank until water flows out over lowest point of the weir. Wait for the level to settle and stop flowing over the weir then press the Zero button. The Height and Out Flow will then be set correctly to zero.

Zeroing the Mass reading

With Height Over Weir correctly zeroed and water at the lowest point of the weir with no water flowing, note the Mass reading then type this value into the Initial Mass box. The Mass reading will then be set correctly to zero so that Mass of Sand and Sediment Yield will be correctly calculated during the exercise.

Operating the Equipment

For details on operating the equipment see Laboratory Teaching Exercises.

Equipment Specifications

Equipment Location

The equipment is designed for installation on a solid floor capable of supporting the weight of the equipment when filled with sand and water. The equipment must be located adjacent to a cold water supply and an appropriate drain at floor level.

Note: This equipment is heavy and must not be moved after filling with sand/water. The floor construction must be adequate to take the point loading of the four support feet. It is therefore important to give adequate consideration to its location before assembling and commissioning the equipment.

Electromagnetic Compatibility

This apparatus is classified as Education and Training Equipment under the Electromagnetic Compatibility (Amendment) Regulations 1994. Use of the apparatus outside the classroom, laboratory or similar such place invalidates conformity with the protection requirements of the Electromagnetic Compatibility Directive (89/336/EEC) and could lead to prosecution.

Environmental Conditions

This equipment has been designed for operation in the following environmental conditions. Operation outside of these conditions may result reduced performance, damage to the equipment or hazard to the operator.

a. Indoor use;

b. Altitude up to 2000m;

c. Temperature 5°C to 40°C;

d. Maximum relative humidity 80% for temperatures up to 31°C, decreasing linearly to 50% relative humidity at 40°C;

e. Mains supply voltage fluctuations up to ±10% of the nominal voltage;

f. Transient over-voltages typically present on the MAINS supply;

   Note: The normal level of transient over-voltages is impulse withstand (over-voltage) category II of IEC 60364-4-443;

g. Pollution degree 2.

   Normally only nonconductive pollution occurs.

   Temporary conductivity caused by condensation is to be expected.

   Typical of an office or laboratory environment.

Routine Maintenance

Responsibility

To preserve the life and efficient operation of the equipment it is important that the equipment is properly maintained. Regular maintenance of the equipment is the responsibility of the end user and must be performed by qualified personnel who understand the operation of the equipment.

General

In addition to regular maintenance the following notes should be observed:

1. The equipment should be disconnected from the electrical supply when not in use.

2. To preserve the life of the pump and to avoid heating of the water inside the pump body, the pump should not be left running when there is no flow of water into the sand tank.

3. Water should be drained from the equipment when it is not in use. After refilling the sump tank with water, the pump should be re-primed by allowing water to flow into the sand tank via the French drains (Refer to the Commissioning procedure in this manual for further details). The pump will be damaged if switched on with the valves closed or outlets not connected.

   Note: The flexible tube connected to the river inlet tank incorporates a quick-release fitting that allows it to be connected to one of the outlets above the flowmeters. This fitting incorporates a self-sealing arrangement to prevent water loss when it is disconnected (prevents water in the tank from draining onto the floor). If it is necessary to drain the river inlet tank then the loose quick-release fitting supplied with the equipment can be connected to the fitting on the end of the tube to allow the water to drain into a bucket. If it is required to drain the water into the sump tank then an additional length of flexible tubing can be connected to the loose fitting as required.

4. The exterior of the equipment should be periodically cleaned. DO NOT use abrasives or solvents.

5. The filters incorporated in the pressure regulators will need cleaning or replacement at regular intervals, the frequency depending on the service conditions. If clean washed sand has used in the sand tank and the water has been changed at regular intervals then annual cleaning is all that will be required. The bowl containing the filter is unscrewed from the body of the regulator to access the filter element. This should be unscrewed as an assembly and replaced with an equivalent or washed as appropriate

   Replacement filter elements can be obtained from:

   Metalwork Group of Companies (Distributors world-wide)

   Part no: FP 1/8 – 1/4 BIT 50 (Colour code: Blue)

6. If the maximum flowrate through the spray nozzles falls below 2.5 litres/min then it will be necessary to clean the nozzles. Each nozzle can be unscrewed using the spanner supplied. The core inside each spray nozzle can be

removed using the Allen key supplied. The nozzles should be refitted after cleaning using PTFE tape to seal the threads.

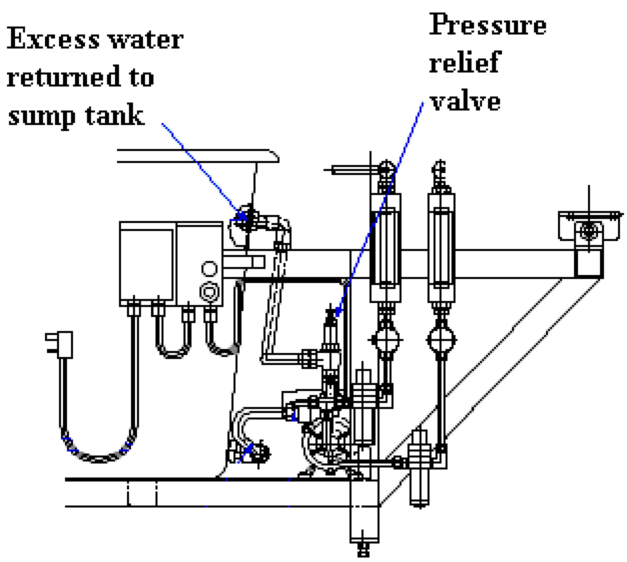
7. After prolonged use the marbles in the river inlet tank will become dirty. The marbles should be transferred to a suitable container, soaked in a weak bleach solution then rinsed using clean water. The river inlet tank should be cleaned using warm soapy water then rinsed using clean water before returning the marbles.

8. After prolonged use the weir chute/diffuser and outlet collecting tank will become dirty. These should be removed from the equipment, washed using soapy water then rinsed using clean water. DO NOT use abrasives or solvents. After cleaning the components replace the clear polythene skirt with slits at the base of the weir chute/diffuser using an elastic band to secure it. This prevents splashing when water and sand fall into the collecting tank.

9. Provided that the ambient temperature is 20°C or less then precautions will not be necessary against Legionella or other hazardous micro-organisms (Refer to the notes on Water-Borne Hazards within the Important Safety Information section). If the temperature of the water will exceed 20°C in use then it will be necessary to take precautions. We would not recommend the use of a strong permanent disinfectant or bleach since the operator will handle the sand when using the equipment. To prevent a hazard to health we would suggest that the tank and pipework (including the spray system) be flushed with a weak hypochlorite bleach solution before using the equipment.

10. Adjusting the pressure relief valve.

    The outlet from the centrifugal pump incorporates a pressure relief valve to limit the system pressure to a maximum of approximately 3.0 barg and prevent the pump from overheating if the flow from the two outlets is restricted or stopped. Water discharging from the relief valve is returned to the sump tank via a connection in the side wall of the tank. When demand from the two outlets is high, the relief valve will remain closed to maintain the pressure in the system. When demand is reduced and the system pressure rises above 3.0 barg, the valve will open to relieve the excess flow.



Start with the pump switched off.

Close the flow control valves below both flowmeters. Ensure that the sump tank is filled to the overflow with clean water.

Remove the cap from the top of the pressure relief valve at pump outlet. Adjust the screw on the pressure relief valve to allow flow to bypass to sump tank without restriction. Adjust both pressure regulators to give maximum flow (pull knob on regulator then turn fully clockwise).

Switch on circulating pump and check that all water is returned to sump tank via relief valve. Gradually adjust setting of relief valve until pressure indicated on gauges of both regulators is 3.2 Bar. Tighten locknut to retain setting of relief valve.

11. Calibrating the electronic load sensor fitted to S12-MKII-50.

    When the optional data logging accessory is fitted, the electronic sensor used to measure the total weight of the outlet collecting tank may require re-calibration. If the reading from this sensor becomes suspicious then it can be recalibrated as suggested below. The PCB is located inside an enclosure below the outlet collecting tank. The potentiometers on the PCB can be accessed by removing the front panel from the enclosure and sliding the PCB forward.

Load Sensor

Remove the outlet collecting tank from the load platform.

Adjust VR2 until 0v (±0.1v) is measured at TP5. Confirm that Current Mass indicates 0 Kg in software.

Place a 5kg weight on the load cell platform then adjust VR1 until 2.5v (±0.1v) is measured at TP5 (5 Kg in software). Remove the weight and check that TP5 returns to 0v (±0.1v) and software returns to 0 Kg).

Replace the PCB in the electrical enclosure and replace the front panel.

Laboratory Teaching Exercises

Index to Exercises

CAUTION: Although the sand tank cannot move suddenly when adjusting the elevation, extreme care should be taken when operating the jacks to prevent crushing of fingers, hands or other objects between the upper and lower frames.

General Equations and Constants

Equations

Discharge (m^3/s) = Discharge (l/min) x (50/3)

Average channel depth (or width) (m) = Sum of depths (or widths) (m) ÷ number of depth (or width) measurements taken

Rainfall Intensity (mm/hr) = ((Rainfall Flow Rate (l/min) x (50/3 ÷ Catchment Area (m^2)) x (5/18)

Sediment Transport Rate (kg/ms) = (Sediment Yield (kg) ÷ Time taken (s)) ÷ Average width (m)

or

Sediment Transport Rate (kg/s) = Sediment yield (kg) ÷ Time taken (s)

Valley Slope (%) = Reading from scale on end of simulator

Darcy's Equation = $$Q = 2\pi r h \frac{dh}{dr}$$

Thiem's Equation = $$s_1 - s_2 = \frac{Q_o}{2\pi k H} \log_n \frac{r2}{r1}$$

Constants

Specific weight of sand = 2650 M/m^3

Specific weight of water = 9810 N/m^3, but alters with water temperature

g (gravitational acceleration) = 9.81 m/s^2

Kinematic Viscosity (m^2/s) = 0.00000114, but varies with temperature

Median Grain Diameter of Sediment Bed = Determine from sand used

Other Equations

Channel cross-sectional area (m^2) = Average channel width (m) x Average channel depth (m)

Wetted perimeter (m) = bed width (m) + 2 x bank height (m)

Hydraulic radius (m) = Channel cross-sectional area (m^2) ÷ Wetted perimeter (m)

Velocity (m/s) = Discharge (m^3/s) ÷ Channel cross-sectional area (m^2)

Reynolds Number = (Velocity (m/s) x Hydraulic radius (m)) ÷ Kinematic viscosity (m^2/s)

Froude Number = Velocity (m/s) ÷ (√ (g x Average depth (m)))

Boundary Shear Stress (N/m^2) = Specific weight of water (N/m^3) x Hydraulic radius (m) x Slope (m per m)

Shear Velocity = √ (g x Hydraulic radius (m) x Slope (m per m)

Boundary Reynolds Number = (Shear velocity (m/s) x Grain diameter (m)) + Kinematic viscosity (m^2/s)

Shields Parameter = Boundary shear stress (N/m^2) ÷ (Specific weight of water (N/m^3) x 1.65 x Grain diameter (m))

Total Stream Power (J/s) = Specific weight of water (N/m^3) x Discharge (m^3/s) x Slope (m/m)

Specific Stream Power (watts/m) = Total Stream Power ÷ width (m) = Velocity (m/s) x Specific weight of water (N/m^3) x Depth (m) x Slope (m per m)

Critical Stream Power (Watts/m) = 290 x Grain diameter $(m)^{1.5}$ x g x Log ((12 x Depth (m)) ÷ Grain diameter (m))

Net Stream Power (J/s) = Total stream power (J/s) – Critical stream power (J/s)

Bagnold's Bedload Equation (kg/ms) = (Net stream power (J/s) ÷ ½ $g)^{1.5}$ x (Depth (m) ÷ $0.1)^{-2/3}$ x 0.1 x Grain diameter (m) ÷ $0.0011)^{-1/2}$

Channel Sinuosity = Channel length (m) ÷ Valley length (m)

Total thalweg length (m) = Sum of all channel thread lengths (m)

Braiding Intensity = Number of sub-channels per unit channel length

Total Sinuosity = Total thalweg length (m) ÷ Valley length (m)

Nickpoint Speed (cm/min) = Distance travelled by nickpoint (cm) ÷ Time taken to move distance (min)

Exercise A - Rainfall-runoff relationships (storm hydrographs)

Theory

Rain falling on a catchment area will make its way to the point of concentration where it will leave the catchment. In a gravity flow situation, this is bound to be the lowest point in the catchment. If the discharge is by means of ground water movement, the situation is more complex and the flow can be distributed over a wide front but as the flow is constrained to leave this model catchment at a single point, we shall not consider this case here.

In practice, a catchment area is defined only once the point of concentration has been fixed and, as steam flow data is needed here, the site of a new pre-existing flow measurement structure is usually chosen. When rain falls on the catchment, the time taken for the water to reach the point of concentration will depend on the horizontal distance it has to travel and also on the velocity.

Figure A1 shows lines of equal flow time for a catchment of similar proportions to the model in which the flow velocity is everywhere the same. Figure A2 illustrates a valley catchment in which the flow velocity is assumed to increase once the water has entered the stream channel. Flow outside the stream could be either by surface or ground water flow, or both.

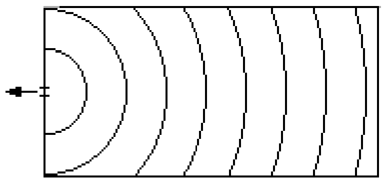


Figure A1

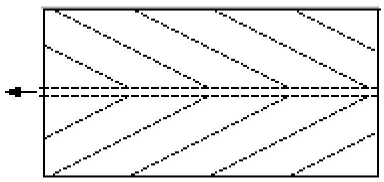


Figure A2

The greatest time taken for rain falling on the catchment (the far corners) is called time of concentration.

A graphical record of flow and time is called a hydrograph and Figure A3 shows a typical hydrograph resulting from a single rainstorm. The timing and intensity of the rainfall is shown by the block in the upper part of this figure and if the rainfall persists for longer than the time of concentration of the catchment, the run-off hydrograph will level off at the peak value on the catchment. Under these circumstances, the recession curve part of the hydrograph is delayed until the rain stops.

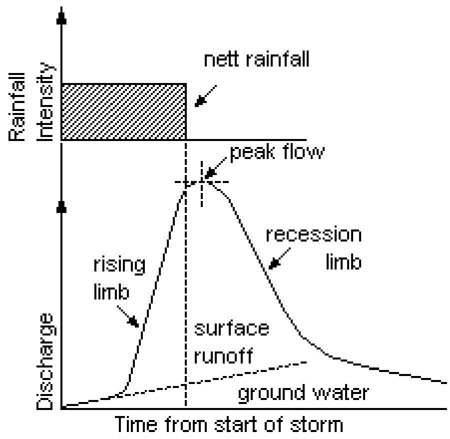


Figure A3

During the early stages of the rainstorm, so long as no recent rain has fallen, the ground will be able to absorb the water falling on it and add it to the ground water already present. When all the voids are filled, the excess must flow over the surface and enter the stream directly as surface flow. It is this surface flow first reaching the point of concentration that produces a sharp rise in the hydrograph and this hydrograph discontinuity can be used to separate the ground water contribution from the direct run-off, as indicated in Figure A3. The hydrograph shown in Figure A3 is typical for storms of duration shorter than the time of concentration of the catchment.

Procedure

Stream flow from a single storm

Before this experiment is carried out, the sand tank should be set to a slope of about 1%. Smooth the sand in the tank to give a smooth surface parallel to the top edge of the tank, then use the sand scoop to create a channel of rectangular cross section centrally down the length of the tank between the river inlet and the deep outlet at the foot. The channel should be approximately 4 cm wide by 2 cm deep.

Connect the flexible piping from the overhead spray nozzles to the quick release connector on the 3 l/min flow meter.

a. Stream Flow for a Long Duration Storm (See Figure A4)

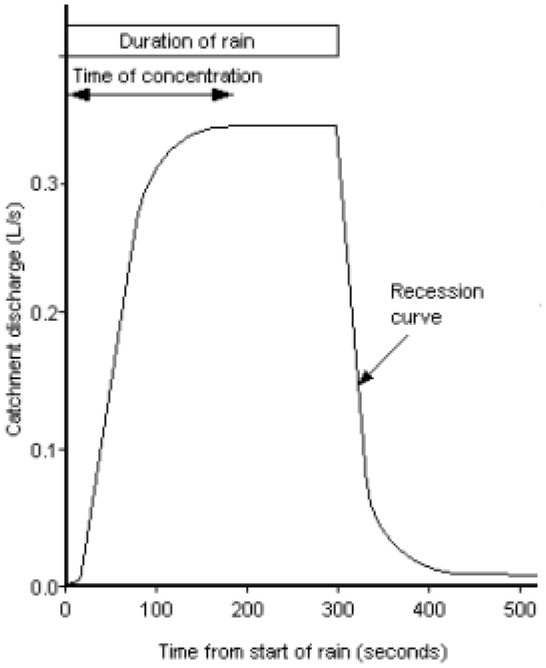
   Turn on the spray nozzles to simulate rainfall and select a rainfall flow rate of between 1 and 3 l/min. Allow rain to fall long enough to give a steady run-off value. Turn off the flow and record the recession limb of the hydrograph. Use a stopwatch started (zero time) at commencement of rainfall, and read weir discharge as frequently as necessary to show the hydrograph form.

   The experiment may be repeated for different rainfall flow rates, smaller catchment areas (by closing some of the valves to the rainfall nozzles) and for small differences in slope.

b. Stream Flow from a Short Duration Storm (See Figure A5)

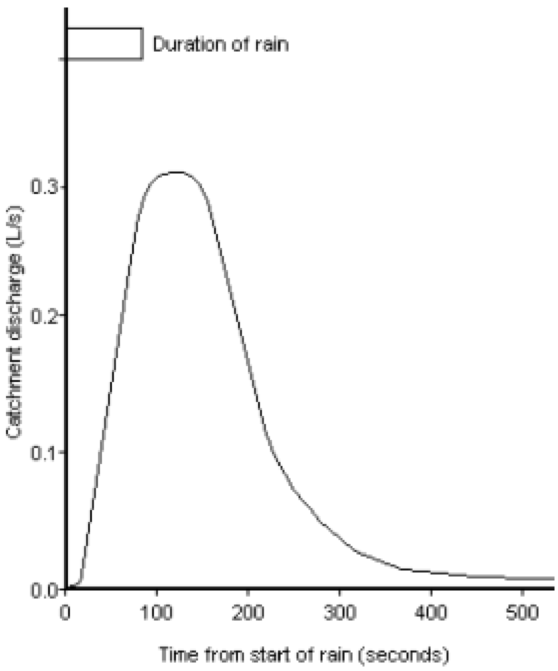
   (Less (60% - 80%) than time of concentration)

Proceed as in a) but cut off rain while hydrograph is still rising Figure A4 will result.



Rain duration greater than time of concentration for catchment

Figure A4



Rain duration less than time of concentration for catchment

Figure A5

c. Histogram

The hydrograph should properly be shown as in Figure A4 and Figure A5 by plotting the results directly.

It may be found that the best-shaped storm hydrographs are obtained when the "rain" is stopped just before the maximum run-off is obtained. That is to say, the duration of the storm is slightly less than the *time of concentration* for the catchment. If the rain persists after the water table reaches the surface then *direct run-off* over the surface occurs. When the rain stops before this occurs, the run-off is only in the form of *ground water* flow.

It is recommended that different slopes and surface profiles be tried until the most suitable hydrograph is obtained.

Stream flow from multiple storms

Connect the flexible piping from the river inlet tank to the quick release connector on the 5 l/min flow meter. Connect the flexible piping from the overhead spray nozzles to the quick release connector on the 3 l/min flow meter.

The sand bed should be allowed to drain following any previous use of the apparatus.

This experiment can be carried out by arranging a first storm of duration rather less (say 50%) than the time of concentration, tc (as obtained in the previous experiment).

Follow it by a second storm of the same duration while the recession limb of the first one is still quite high. The discharge values must be recorded continuously from the start of the first storm, and the resulting double hydrograph when plotted will show the much larger run-off values obtained for the second storm which falls on a previously saturated catchment. The method for drawing the hydrograph, outlined in "Stream Flow for a Single Storm", may be used.

Stream flow from an impermeable catchment (urbanisation)

After investigating the rainfall run-off relationships for a permeable catchment, it is of interest to reduce the permeability of the catchment surface by covering part or all of it with the impermeable Polythene sheet provided with the accessory items. If only the upper part of the catchment (away from the discharge end) is sealed in this way, then the run-off from the plastic sheet is lost in the sand in the lower part. If, however, the lower part of the catchment only is covered, the run-off is more immediate and the effect on the hydrograph more marked. The plastic sheet provided should be trimmed with a knife or scissors to fit the required catchment area.

Stream flow from a highly vegetated catchment

The effect of a highly vegetated catchment may be simulated by covering part or all of the catchment surface with the absorbent material provided.

Stream flow with reservoir storage

The effect of a flood detention reservoir on the run-off from a standard storm can be demonstrated by using the accessories provided. The circular ended ring can be used when partly buried in the sand to form a circular reservoir, and the closed ring can, similarly, be used to retain the rain that falls on it and to release the water slowly through the centre aperture. It may prove necessary to use all available vessels to simulate detention reservoirs and it will be found that inverted dustbin lids serve well so long as they have a small drainage hole made in their centre.

Effect of land drainage on run-off hydrograph

One of the commonly employed methods of improving land drainage is the construction or renewal of ditch systems. Different model ditch systems can be constructed on the sand surface in the catchment tank and their effects on the run-off hydrograph of a standard storm compared.

Results

Description of catchment area and initial channel planform:

Sketch of catchment area:

Time since start of run (secs)	Rainfall flow rate (l/min)	River inlet flow rate (l/min)	Flow rate over weir (l/min)

Plot graphs (run-off hydrographs) of run-off flow rate against time since start of rainfall for each set of data.

Conclusions

Discuss the results obtained in the experiments performed. Describe the shape of each hydrograph, and comment on the effects of each parameter on the run-off experienced. Suggest reasons for any deviation from the expected results.

Exercise B - Generation of overland flow

Theory

Overland flow is the rainfall that fails to infiltrate the surface and subsequently travels over the ground until it reaches channel flow, infiltrates or evaporates. It is rarely seen, but may be important in a number of situations, for example where ground conditions are saturated or frozen, or where the soil is highly compacted or very dry. Overland flow generally forms part of the quickflow element of the runoff process, and can vary considerably from catchment to catchment. The process of overland flow has important hydrological consequences, as it acts as a strong influence on the variation of streamflow with time in a catchment corresponding to a rainfall event.

Procedure

Connect the flexible piping from the overhead spray nozzles to the quick release connector on the 3 l/min flow meter.

Set the sand tank to a slope of between 3.5% and 4.5%. Mould the sand into a miniature drainage basin. This should include a central channel or valley leading to the deep cut-out at the foot of the tank. Include areas where overland flow would be expected to form, such as areas close to the water table and/or areas of flow convergence. Keep the topography simple to allow a clear drainage system to develop. Record the topography created, noting areas of high and low slope and elevation.

Decide on the rainfall event to be simulated. The following options are all possible:

- Prolonged low-intensity rainfall
- Short high-intensity rainfall
- Alternating intensity rainfall
- Multiple rainfall events

Observations of the sediment bed should be made throughout the simulation, noting the rainfall flow rate, outlet flow rate, and when and where the development of overland flow was seen. The development of source areas should also be recorded once overland flow has commenced. At the end of the rainfall event, observations should continue until the simulator has drained for 30-45 minutes.

The experiment may be repeated with a variation in a single characteristic, such as rainfall intensity or topography, to determine the effects of these controls.

Results

Description of catchment area and initial channel planform:

Sketch of catchment area:

Time since start of run (secs)	Rainfall flow rate (l/min)	Tank outflow rate (l/min)	Location and direction of overland flow, including source areas (use references to sketch above)

Conclusions

What conditions produced the best examples of overland flow? What factors may have contributed to its development? Did overland flow appear to produce significant surface erosion or channel planform change? Suggest ways in which overland flow could be reduced or prevented.

Exercise C - Initiation and characteristics of bedload motion

Theory

Sediment can be transported along a river channel in three ways. Wash load originates in slope runoff and bank erosion, and is controlled by sediment supply rate rather than the river's ability to transport sediment. The dissolved load represents the portion of sediment that is carried in solution, and derives from rock and soil weathering. This generally decreases with discharge and normally has no effect on alluvial channel form. Bed load material is composed of sediment originating in the channel bed and bank. Bed material load is relatively coarse and moves as bed or near-bed load and is almost entirely a function of the flow's ability to transport material and requires an understanding of how and why material is transported.

Water flow along an open channel is controlled by two opposing forces. The downstream or driving force results from the downstream component of the weight of the water, and is therefore governed by gravitational laws. This force may be divided by the area over which it acts to obtain the bed shear stress. The opposing upstream force is generated by friction between the water and the sediment of the channel boundary.

To remain stationary the boundary sediment must supply an equal opposing force to that associated with the bed shear stress. The opposing force derives from friction and interlocking between grains. Bed shear stress increases with flow intensity (γO), at a rate approximately equal to the square of the mean velocity. If the bed shear force exceeds the opposing friction force then the geomorphological threshold of motion (γCR) is crossed, and sediment grains start to move along the channel bed.

At flow intensities just above the threshold of motion, sediment particles move by *rolling* and sliding along the bed. As flow intensity increases, grains lift out of the bed and bounce along the channel following ballistic trajectories. This motion is thought to be promoted by the effect of fluid lift force, and the particles are said to be *saltating*. Sediment grains travelling by rolling, sliding or saltating are all in frequent or continuous contact with the channel bed and are classified as *bedload*. At higher flow intensities sediment particles are carried in the flow continuously by *suspension* due to anisotropic turbulence. Suspended bed sediment and the wash load combine to form the *suspended load*.

The force required to move the boundary sediment is influenced by several factors, including sediment grain size and sediment position (as particles on the channel bank are subjected to different levels of force than those on the channel bed). Once a particle is in motion, less force is required to keep it in transport. The threshold of motion is highly important as it marks the onset of processes of sediment transport, erosion and, in turn, deposition. These processes are responsible for morphological adjustment of the fluvial system and hence the threshold of motion marks the point at which the flow starts to control the shape of the channel.

Procedure

Connect the flexible piping from the river inlet tank to the quick release connector on the 5 l/min flow meter.

Set the slope of the sand tank to between 0.6% and 0.8%. Smooth the sand level, parallel to the top of the tank, and lightly tamp it down. Use the scoop provided to cut a straight * trapezoidal channel into the sediment bed, from the river inlet tank to the deep cut-out at the foot of the tank. The channel should be approximately 5 cm deep and 10 cm wide.   Record the channel dimensions.

Set the river inlet flow rate to 1.5 l/min and allow time for the sediment bed to become saturated. Surface flow should then occur along the channel. If bedload motion is observed, reduce the channel slope, reform the initial channel and restart the experiment. Record the depth and width of flow in at least ten randomly selected places along the channel. As the inlet and outlet will both affect the local hydraulics and channel behaviour, ignore the uppermost and lowermost 30 cm of the main channel when taking recordings.

Increase the slope slightly until you observe that grains of bed sediment start to move. This is the threshold of motion. Make careful observations to establish whether there is in fact a specific threshold of motion, or whether the onset of motion is more gradual.

Slowly increase the valley slope in 0.6%-0.8% stages up to the maximum slope of the simulator, making observations and taking sediment yield measurements at each stage. Each run should last for 20-25 minutes, with sediment yield measured every five minutes (or more frequently for high sediment flow rates). The channel should be left for 5-10 minutes at each setting before taking recordings, to allow the transport rate to adjust to the new flow rate. It should be possible to observe sediment transport by rolling, sliding and saltation processes described in the theory earlier. Depending on the calibre of sediment used to form the bed of the channel, suspension may occur at the higher flow rates.

The experiment may be repeated for different initial flow rates if desired.

* If a meandering channel is used then motion will be initiated at the bends well before the straight sections. Sediment eroded from each of the bends will be deposited at the next inflection point downstream. Is this the intention? It seems to complicate the threshold of motion rather than clarify it to me. I suggest using a straight channel at least in the first instance.   A meandering channel could be used in a subsequent experiment to investigate the influence of non-uniformity of the channel on the threshold condition.

Results

(Produce one table for each slope setting)

Inlet Flow Rate ______ l/min

Valley Slope ______ %

Elapsed time (min)	Sediment transport rate (g/min)	Channel width (m)	Channel depth (m)	Observations of sediment transport processes

Conclusion

Basing your conclusion on your observations, is there a specific threshold of motion for river bedload? If so, is there a defining relationship between bed slope, river flow rate, Shields parameter and initiation of bedload motion? Are there any other factors that also appear to have an effect on the initiation and characteristics of sediment movement?

Exercise D - Effect of changing stream power on channel morphology

Theory

Channel planform reflects the hydrodynamics of flow within the channel and the associated processes of sediment transportation and energy dissipation. There is no current theory that can fully predict channel form, but it can be demonstrated that the channel morphology changes in response to stream power, sediment load and bank stability. There are three basic channel types: straight, meandering, and braided although in nature these types form a continuum of planform patterns. A river may exhibit combinations of these types along its length or at different discharges at a given location, and few rivers display a clear example of a particular channel type for any great distance.

A straight channel has straight banklines, but may possess a meandering thalweg. A meandering channel follows a winding course that may be approximated by a sine-generated waveform. In a braided channel, flow occurs through multiple sub-channels that thread their way through a series of bars within the broadly straight channel.

Straight channels rarely occur in stretches longer than ten channel widths. They are relatively stable features, and are either geologically controlled or have insufficient energy to move significant quantities of boundary sediment. A high proportion of any sediment load is likely to be carried as suspended load. Straight channels may have a meandering thalweg, which develops due to coherent, three-dimensional turbulence structures generated in the corners of trapezoidal channels.

Meandering channels are the most common river type, although the degree of meandering can vary considerably. Meandering is associated with intermediate valley slopes (steeper than those of straight channels, but less than those leading to braiding), bed sediment moving as mixed bedload and suspended load and somewhat erosion resistant banks. Channel sinuosity is a primary indicator of meandering. Meander wavelength, amplitude and arc length are also used to represent channel conditions. The extent of meandering, sinuosity, wavelength, amplitude and arc length all tend to increase with the relative energy of the channel system.

The meandering tendency in straight channels is self-strengthening because of the positive feedback between flow curvature and flow scour. This feedback also leads to the characteristic, growth and migration of meanders as a result of selective bank erosion and point bar development. Feedback occurs because as the channel curves the fastest flow is skewed towards the outside of the channel, promoting erosion at the outer bank and deposition at the inner bank that through time results in bend growth and migration. This process also results in a close association between channel cross section and position with respect to the meander wavelength. At a bend apex, the cross-section is highly asymmetrical with a deep thalweg close to the outer bank and a shallow bar at the inner bank. At the inflection point between bends, the cross-section is more symmetrical with the lower scour depth. The identification of strong secondary flow cells that focus maximum erosion towards the foot of the outer bank in meander bends was a major step forward in the understanding of meander processes.

Braided channel patterns predominantly develop in high energy fluvial environments with relatively steep valley gradients, large and variable discharges, dominance of bedload transport over suspension and easily eroded non-cohesive banks. The onset of a braided planform is a significant geomorphic threshold within the planform continuum, as it marks the point where flow switches from a single thread to multithread configuration. Braiding intensity and total sinuosity are used to characterise the morphology of braided channels.

Procedure

Connect the flexible piping from the river inlet tank to the quick release connector on the 5 l/min flow meter. Fit one of the two 50 mm stop logs into the deep cut-out at the foot of the tank.

Adjust the slope of the sand tank to 0.5%. Smooth the sand level and parallel with the top of the tank. Use the scoop provided to cut an initial straight channel from the river inlet tank to the deep cut-out at the foot of the tank. The channel should be approximately 4 cm wide and 2 cm deep. Set the river inflow rate to approximately 2 l/min.

Observe the channel during the development of an alluvial channel environment. Record the sediment yield every 10-15 minutes. Record the topography of the bed every 30 minutes (the flow may be turned to a low level during measurement, so that the channel does not change during this time). Make notes on the presence of features such as bars, terraces, scour holes, and the position of the channel thalweg. Measure the channel length by laying a piece of string along the edge of the channel. The length of the thalweg can be measured in a similar manner.

The entrance and exit effects of the inlet and low cut-out will affect the channel shape, and it is advisable to avoid the uppermost and lowermost 30cm of the channel when taking measurements.

Continue to take measurements in this manner for four to five hours. Note that if there is no initial sediment load introduced into the inlet flow, the channel will incise into the top of the sediment bed, which will gradually reduce the slope and stream power over the course of the run. Hence, it is advisable to add a small amount of sediment at the head of the channel as necessary to maintain the bed level.

The experiment should then be repeated at increased stream power. Stream power may be increased by increasing the valley slope, or by increasing the inlet flow rate. Several runs should be made in order to build up a comprehensive set of data covering a variety of stream powers and channel planforms. The time requirement may be decreased by changing stream power every 3-4 hours without resetting the sediment bed, but accuracy will be reduced.

Results

Inlet Flow Rate ______ l/min

Valley Slope ______ %

Elapsed time (min)	Sediment yield (g/min)

One method of making diagrams of the channel requires two rulers or measuring sticks, both of which must be rigid and one of which must be at least 1 metre in length. This long ruler should be laid across the top of the tank from one side to the other, parallel to the end, and then moved along the tank in steps of 10 cm. At each position, the second ruler is then used to measure the distance from the top line of the tank to the sand surface, in steps across the entire width of the tank. Reference points should be recorded for any notable features such as the positions of the channel sides, sand bars, sub-channels and thalwegs.

Channel length may be measured by laying a piece of string along the side of the channel, then noting the length of the string. Thalweg length may be measured in a similar fashion.

Conclusion

Describe the development of the channel cross-sectional and planform morphology and the features noted during the experiment, relating this to the initial conditions, river flow rate and rate of sediment transport (sediment yield). Discuss the relevance of laboratory simulations to real-world situations.

Exercise E - Effect of base level change

Theory

The third dimension of adjustment in alluvial channel morphology is the long-profile. The long-profile can adjust through changes in bed elevation, channel gradient, and overall profile shape. Bed elevation changes occur through aggradation and degradation, and reflect the channel's ability to transport sediment. Base level represents one particularly important control on channel profile.

A reduction in downstream base level leads to channel degradation, initiating incision as a *nickpoint* forms and travels upstream. As the nickpoint migrates upstream, the sediment generated by it may drive aggradation downstream. In time, secondary nickpoints may appear downstream of the primary nickpoint and aggraded area, and the steepened area containing these nickpoints is referred to as the *nickzone*. The sequence of channel adjustments resulting from nickpoint migration and local aggradation has been termed complex response because a single baselevel lowering event can generate multiple step changes in bed level. The overall channel degradation resulting from a fall in base level is a regional phenomenon that involves the progressive and sustained net lowering of the bed over long distances and timescales.

An increase in base level leads to aggradation and channel change through the development of a deltaic type of deposit. Aggradation is a result of the channel having insufficient energy to transport the sediment supplied from upstream and it characteristically results in loss of channel conveyance capacity and localised flooding.

Procedure

Connect the flexible piping from the river inlet tank to the quick release connector on the 5 l/min flow meter. Fit one of the two 50mm stop logs into the deep cut-out at the foot of the tank.

Set the slope of the sand tank to approximately 2%. Smooth and lightly tamp down the sand level with the top of the sand tank. Use the scoop provided to cut an initial straight channel into the sediment bed from the river inlet tank to the deep cut-out. The channel should be approximately 4cm wide and 2 cm deep.

Set the inlet flow rate to 2.5-3 l/min. Observe the channel during the development of an alluvial channel environment. Record the sediment yield every 10 minutes. Record the topography of the bed after 30 minutes (the flow may be turned to a low level during measurement, so that the channel does not change during this time), and again after 60 minutes. Make notes on the presence of features such as bars and terraces, and particularly record the position of the channel thalweg. Measure the channel length by laying a piece of string along the edge of the channel. The length of the thalweg can be measured in a similar manner.

To simulate an increase in base level, add one or more additional stop logs to the deep cut-out. To simulate a drop in base level, remove the stop-log already in position. Observe the changes carefully, continuing to record the sediment yield rate and channel planform at regular intervals (15-30 minute intervals for channel planform, depending on the speed of morphology change). For a drop in base level there will be an initial rush of sediment, and sediment yield will have to be recorded every two minutes until the nickpoint has migrated upstream away from the outlet.

For a rise in base level, the observations should include a record of the position of the nickpoint, and of any secondary nickpoints that appear.

Results

Elapsed time (min)	**Sediment yield** (g/min)

One method of making diagrams of the channel requires two rulers or measuring sticks, both of which must be rigid and one of which must be at least 1 metre in length. This long ruler should be laid across the top of the tank from one side to the other, parallel to the end, and then moved along the tank in steps of 10cm. At each position, the second ruler is then used to measure the distance from the top line of the tank to the sand surface, in steps across the entire width of the tank. Reference points should be recorded for any notable features such as the positions of the channel sides, sand bars, secondary channels and thalwegs.

Conclusion

Describe the response of the channel to base level change. What factors appear to contribute to rate of nickpoint migration for a fall in base level? What factors affect the rate of aggredation for a rise in base level? What real world situations might produce base level change in a river environment?

Exercise F - Scour in open channel flow

Theory

Local conditions can affect channel flow. These can be natural conditions, but man-made obstructions and artificial structures are becoming increasingly common. Changes in land use can also affect channel conditions by altering runoff, transpiration and evaporation rates. Local conditions do not necessarily have local effects, as the river environment is a complex system with many interrelated parts.

One of the most common type of artificial structure is a solid obstruction placed in the channel flow, such as a bridge pier or groyne. General and local scour are two similar morphological responses to such flow obstruction. General scour is a site-specific phenomenon involving bed lowering in a reach over a long period, or only during high flow events. It is usually caused by an accelerating flow velocity through a narrowed channel width.

Local scour is a local phenomenon where a section of the bed is lowered in response to increased velocity and turbulence adjacent to a solid obstruction. Channel response can be seen in both upstream and downstream directions. On the upstream side a horseshoe vortex develops and results in the formation of a scour trench. On the downstream side a line of vortices called a *vortex street* is produced.

Procedure

Connect the flexible piping from the river inlet tank to the quick release connector on the 5 l/min flow meter. Fit one of the two 50mm stop logs into the deep cut-out at the foot of the tank.

Set the slope of the sand tank to approximately 2%. Smooth and lightly tamp down the sand level with the top of the sand tank. Use the scoop provided to cut an initial straight channel into the sediment bed from the river inlet tank to the deep cut-out. The channel should be approximately 4cm wide and 2cm deep.

Switch on the pump and set an inlet flow rate of 2 l/min. Allow the channel to develop for 30 minutes. Sediment yield and channel discharge may be recorded if desired, but this is not essential.

Accessories may be placed in the channel in order to simulate bridge piers, groynes, vanes and so on. These items should be partially sunk into the streambed to prevent movement during the run. A variety of shapes have been provided so that the effects of streamlined, flat-ended and cylindrical shapes may be investigated. Other items may be used to simulate additional flow obstructions, such as a pebble to represent a boulder. Any such items must be heavy enough to remain motionless in the flow.

Place the chosen object into the main channel approximately one third of the way down the sand tank from the river inlet. Any changes in channel shape and the development of any scour holes and sediment depositions should be observed and recorded. Flow turbulence and eddies may be located by observing the reflection of light off the water surface.

Increase the valley slope in increments of 0.3-0.5%, observing the development if the scour hole and the channel along the length of the sand tank. The channel should be left for at least 15 mins after each change in slope. Scour hole geometry, channel width and depth, discharge, sediment yield and valley slope may be recorded if desired.

The experiment may be varied by altering the position of the obstruction within the width of the channel, and by using multiple obstructions.

Results

Diagrams of the channel planform, flow obstructions, flow turbulence and scour features should be made for each set of conditions.

Valley slope (%)	**River discharge (l/min)**	**Sediment yield (g/min)**

One method of making diagrams of the channel requires two rulers or measuring sticks, both of which must be rigid and one of which must be at least 1 metre in length. This long ruler should be laid across the top of the tank from one side to the other, parallel to the end, and then moved along the tank in steps of 10cm. At each position, the second ruler is then used to measure the distance from the top line of the tank to the sand surface, in steps across the entire width of the tank. Reference points should be recorded for notable features such as the positions of the channel sides and any flow turbulence and eddies. More detailed sketches should be made of scour hole geometry.

Conclusion

Describe the way in which the shape of an obstruction influences the amount of scouring of the river bed and sides. If multiple obstructions were investigated, comment on the effect of spacing, both across the channel and down its length. Can any conclusions be drawn from the experimental model on the best positioning of bridge piers across a river to minimise scour, and on the best cross-section for the base of such piers? What other factors may need to be considered when designing an artificial river structure such as a bridge or groyne?

Exercise G - Water abstraction from a well in a confined aquifer

Theory

An aquifer is a water-bearing layer in the ground in which horizontal flow is possible due to its inter-connecting void structure. These pores through which the flow takes place may be very small indeed and, generally, are between the limits 2mm - 0.02mm. The movement is slow compared with surface run-off and the flow is usually laminar. The Reynold's Number in flows of this kind is very low.

A confined aquifer is one which is capped by an impermeable stratum and, assuming horizontal plane boundaries, all subsequent water movement must be in horizontal paths. Recharge on the aquifer can therefore occur only where there is a break in the permeable cover.

If the aquifer is fully saturated then the water will rise in a borehole, which penetrates the cover until an equilibrium pressure is obtained at the bottom of the borehole.

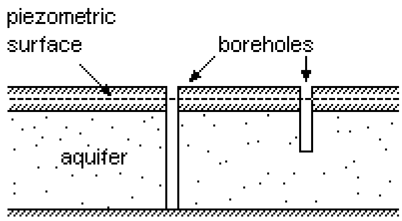


Figure G1

The imaginary surface which contains the water surfaces in any such boreholes is called the piezometric surface and can be thought of as extending in all directions, see Figure G1. If the piezometric surface lies above the ground surface, water will flow from a borehole penetrating the aquifer without the assistance of a pump. This now constitutes an artesian well.

When there is no ground water movement the piezometric surface must be horizontal and plane. Under these circumstances, the water will rise to the same level in any boreholes present. If water is removed from a well by pumping, the piezometric surface is depressed locally as water flows towards the well through the aquifer. This is the situation shown in Figure G2, and Darcy's Equation relates the local water velocity in the aquifer to the slope of the piezometric surface above.

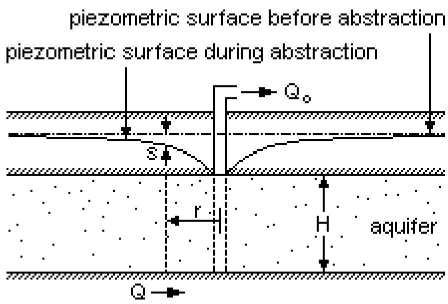


Figure G2

$$Q = v.2\pi rH = k\frac{ds}{dr}2\pi rH \quad (1)$$

and the equation of continuity.

$Q = Q_o =$ constant, leads to Thiem's Formula

$$s_1 - s_2 = \frac{Q_o}{2\pi kH}\log_n\frac{r2}{r1} \quad (2)$$

in which

Q = total rate of low in aquifer at radius r

v = water velocity in aquifer at radius r

H = thickness of aquifer

k = coefficient of permeability of aquifer

s = lowering of piezometric surface at radius r (from rest position)

Q_o = steady discharge from well.

The coefficient of permeability has the dimensions of a velocity and typical values are in the range 0.04 to 0.004 mm/s.

Procedure

Abstraction from a single well in a confined aquifer with radial symmetry

The well placed centrally in the catchment tank is used in this experiment. A shallow depression is scooped in the sand until the top of the gauze well tube is exposed. A flat sand surface is now prepared at this level, large enough to take the closed ring, arranged with its centre opening over the well tube. The closed ring is now placed in position with its transparent central standpipe (sight tube) in position, and a shallow trench is excavated in the sand outside its periphery (see Figure G3).

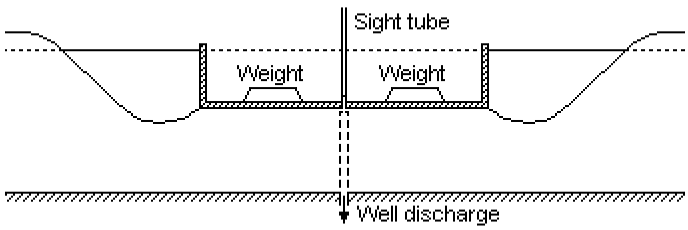


Figure G3

Connect the flexible piping from the two French drains to the quick release connector on the two flow meters- these will be used as inlet pipes not as drains for this experiment. Maintaining equal flow through both flow meters, flood the sand until the water level surrounding the closed ring is just below its rim or, if this level is not possible, as near below as is possible. It will be necessary to weight the closed ring to stop it floating when the bed is flooded, approximately 10 kg weight. Items used for this must be suitable for use in water and must not damage the ring. The water level in the sight tube must also be observable with the weights in place.

The closed ring forms the upper impermeable stratum confining the aquifer (sand) and so producing the required radial flow distribution. It will be necessary to determine the depth of the aquifer (H) to use in equation (1) in "Water Abstraction from a Well in a Confined Aquifer". Now if values r_1 and r_2, s_1 and s_2 are obtained from either the manometer pressure tappings or the water levels in the peripheral trench and the sight tube, the value of the coefficient of permeability (k) can be found.

Q_o must, of course, be measured from the flow leaving the well. To do this, the outflow pipe should be diverted into a measuring cylinder to collect the outflow over a timed period. It will be necessary to balance the inflow valves so that the well abstraction does not lead to a falling water table while readings of s and Q_o are being taken. It is also important to check that a water surface is visible in the sight tube to ensure that the aquifer remains fully saturated in the region close to the wall.

Graphs showing the level of the piezometric surface in sections along the axis of the tank and at right angles to it can be plotted from the manometer readings. It is also possible to prepare a plan from these graphs showing piezometric surface contour lines.

Abstraction from a single well in a confined aquifer of rectangular plan

The apparatus is set up in exactly the same way as described in "Abstraction from a Single Well in a Confined Aquifer with Radial Symmetry", except that the large rectangular closed ring is used to seal off the top of the aquifer. For any shape confined aquifer a variation of Thiem's Formula, (1) in "Water Abstraction from a Well in a Confined Aquifer", relates the drawdown of the water surface in a well to that of the piezometric surface above the neighbouring aquifer.

$$\frac{Q_o}{2kH}\log_n\frac{R_o}{r} \quad \text{(Dupuit formula)} \qquad (3)$$

in which s is the drawdown of the piezometric surface at a radius r from the well and R_o is the integration constant described below. This equation holds good only for the area close to the well (r small) and, using a k value determined in "Abstraction from a Single Well in a Confined Aquifer", the elevation of the piezometric surface can be calculated using equation (3). For a confined aquifer Ro has the value where $\frac{D}{2}$ is the diameter of the constraining cap and, in a rectangular plan aquifer of width 2L, R_o has the value 1.27 L (Fig. G4).

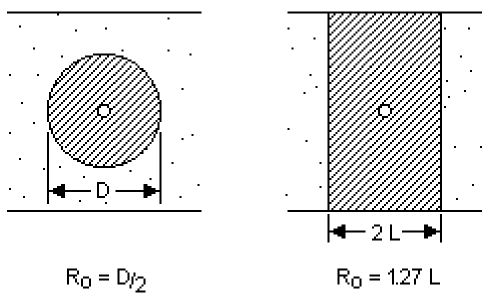


Figure G4

It is suggested that values of s are computed using the measured value of Qo and equation (3), (with the appropriate value of Ro) and a line is then drawn on a graph of s against r to represent these values. Further points can now be drawn on the same graph from the measure values obtained with the manometer tubes.

Results

Volume collected l	Time to collect sec	Q_0 m^3/s	H m	Tapping position m	Manometer readings m	S (=H-manometer reading)

Calculate k from one of the two equations provided in the theory.

Conclusion

Compare the results obtained with typical permeability values of different types of aquifer.

Exercise H - Water abstraction from a well in an unconfined aquifer

Theory

Fig. H1 shows an unconfined aquifer situated above an impervious base. There is no recharge by rainfall or loss of water by evapo-transpiration and the water table is consequently horizontal. In an unconfined aquifer the piezometric surface coincides with the upper limit of the saturated zone and this is commonly termed the water table.

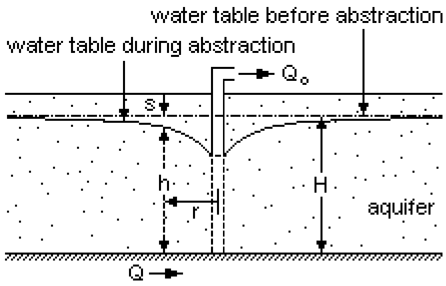


Figure H1

Ground water abstraction from a well will again result in the lowering of the water table but, in the unconfined aquifer under consideration, this means at the same time a reduction of the saturated depth available for the flow of water. The equations of flow thus become:

Darcy $$Q = 2\pi r h \frac{dh}{dr}$$

continuity Q = constant = Q_o

combining hdh $$\frac{Q_o}{2\pi k} \cdot \frac{dr}{r}$$

integrated h^2 $$= \frac{Q_o}{\pi k} \log_n r + C$$

or in the form of the Dupuit Formula

$$H_2 - h^2 = \frac{Q_o}{\pi k} \log_n \frac{Ro}{r} \qquad (1)$$

in which the integration constants Q_o and R_o must be determined from the boundary conditions.

In this case

H = depth of saturated zone before pumping

h = (H - s) where

s = lowering of the water surface due to pumping.

By substituting (H - s) for h this lead to the equation of Thiem.

$$s_1 - s_2 = \frac{Q_o}{2\pi kH} \log_n \frac{r2}{r1} \qquad (2)$$

Procedure

Cone of depression for a single well in an unconfined aquifer

For this experiment no cap is placed over the sand in the area of the well and the sand surface should be horizontal and flat. Ensure that the drain valves for the two cylindrical wells are both in the closed position. Connect the flexible piping from the two French drains to the quick release connector on the two flow meters- these will be used as inlet pipes not as drains for this experiment. Maintaining equal flow through both flow meters, flood the sand until the water level in the manometer tubing is just below the sand level in the tank. Open the drain valve beneath the well set centrally between the manometer tapping points (the right-hand well when facing the apparatus from the side holding the flow meters and manometer array). Adjust the flow and drain valves to give a good draw-down at the well (as displayed on the manometers) and steady conditions.

Graphs of water table elevation can be drawn from the manometer readings for abstraction from the centrally placed well and, from these, a contour plan of the water table surface may be prepared. So long as the coefficient of permeability k has been determined by the method above, theoretical values for s can now be determined from the equations provided and compared with the plotted experimental values. Dupuit's formula in the form given in equation (1) can be used for small drawdowns in the area close to the well (take value of R_o equal to half the width of the catchment tank), while Thiem's formula, equation (2), can be used for the more distant areas.

As in the other well experiments, Q_o, the discharge must be measured. To do this, the outflow pipe should be diverted into a measuring cylinder to collect the outflow over a timed period. It will be necessary to balance the inflow valves so that the well abstraction does not lead to a falling water table while readings of s and Q_o are being taken. It is also important to check that a water surface is visible in the standpipe to ensure that the aquifer remains fully saturated in the region close to the wall.

Results

Volume collected **l**	**Time to collect** **sec**	**Q_0** **m^3/s**	**H** **m**	**Tapping position** **m**	**Manometer readings** **m**	**S** **(=H-manometer reading)**

Calculate k from one the equation provided in the theory.

Conclusion

Compare the results obtained with typical permeability values of different types of aquifer.

Exercise I - Water abstraction from a number of neighbouring wells

Theory

From Exercise H,

$$s_1 - s_2 = \frac{Q_o}{2\pi kH} \log_n \frac{r2}{r1} \qquad (1)$$

The method of superposition allows the prediction of a complex situation by considering it to be made up of a number of simple elements and superimposing their resulting individual effects as described by the above equation. In the case of neighbouring wells in the same aquifer, the linear relationships essential to the use of this method are to be found in confined aquifer flow because the saturated depth of the aquifer remains unchanged and the coefficient of transmissibility is constant.

The flow of ground water in an unconfined aquifer is always accompanied by a change of the saturated thickness zone of flow. For ground water abstraction with wells, the coefficient of transmissibility thus also depends on any previously existing ground water movement, for example, that due to a neighbouring well. This means that the method of superposition can be used only in its simple linear form if the separate drawdowns are small compared with the saturated thickness of the aquifer.

Procedure

This experiment is carried out using an unconfined aquifer with water inflow at both ends of the tank. The set up is the same as for Exercise H, but this time both cylindrical wells are used. The method of superposition applies only to small drawdown values, it is suggested that small Qo values should be used.

Draw the required flows from each well in turn, measuring the drawdown produced in each case with the manometers. Now establish the combined well flow (both wells at the same time) and measure the resulting water table drawdowns. It should be possible, according to the principle of superposition, to synthesise this combined water table pattern by adding the values obtained with each well flow independently. For this experiment the drawdown close to the well should not exceed 25% of the saturated thickness of the aquifer before drawdown.

It is also of interest to explore the drawdown due to much larger abstractions from these wells. Although the superposition principle will not apply, it is possible to determine the effect of a nearby abstraction on the cone of depression of another well and to relate the size of these interactions to the relative flows discharged by the wells.

Dewatering an excavation site

A deep excavation for the purposes of foundation construction or other below-ground activity will frequently penetrate below the natural rest level for the water table in that area. If the excavation is in permeable ground this will constitute an aquifer and the excavation will fill with water to the local water table level due to ground water flow. One method of keeping such an excavation dry is to sink a ring of wells around the outside of the excavation site and to lower the water table locally by pumping the well system.

In this experiment, the small square open ended ring is used to form the sides of the excavation by sinking it in the sand between the two well positions and removing the sand inside down to the lower level of the ring wall. If the sand in the catchment tank is now saturated by admitting water via the inlet control valves, the "excavation site" will fill with water. Now lower the water table by opening the well drain control valves until the excavation dries out. Plot a profile along the centreline of the tank showing the position of the water table (from the manometer readings) in relation to the wells and excavation cross-section.

Normally, of course, more than two wells would be used and so in this case difficulty may be experienced in getting the bottom of the excavation site completely dry.

Draining a polder or lake

This situation differs from the excavation dewatering problem in that the drainage takes place from the floor of the polder. This means that ground water flows into the polder, is collected in a ring ditch near the wall and pumped out from one or more points. In this experiment the polder bank is represented by the large rectangular open ended ring which is positioned to enclose the two wells. The sand is removed from inside as before and a circular ditch formed in the bottom to link both of the wells (Figure I1).

The sand is now flooded and the well control valves are opened until the polder is drained and the inlet valves adjusted to keep the water table elsewhere at the sand surface. It is possible to carry out this experiment without using the square ring, by forming a natural polder bank with the sand at a stable slope (Figure I2). The position of the water table should be determined from the manometer tubes and profiles plotted to show this in relation to the ground surface and well positions.

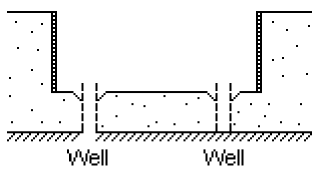


Figure I1

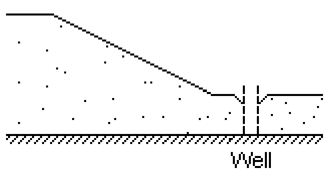


Figure I2

Results

Volume Collected (well 1) l	Time to Collect (well 1) sec	Q_0 (well 1) m^3/s	Volume Collected (well 2) l	Time to Collect (well 2) sec	Q_0 (well 2) m^3/s	Tapping Position m	Manometer Readings m	H m	S (= H - manometer reading)

Conclusion

Did the results observed fit with the results predicted by theory? Suggest reasons for any differences.

Exercise J - Rainfall on a circular island with a central well

Theory

It is suggested that students read the theory of superposition described in Exercise I before proceeding with this experiment.

Procedure

Connect the flexible tubing from the spray nozzles to the quick release connector on the 5 l/min flow meter. The circular ended ring should be placed on the sand concentric with the central well. The ring should then be pushed into the sand until only half remains visible, and the inside volume should now be filled to the rim with sand excavated to form a ditch just outside the ring (see Figure J1).

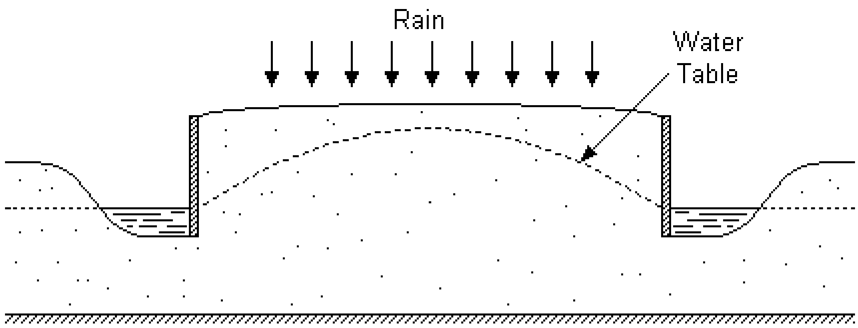


Figure J1

This ditch must connect with a second straight one linking it to the end outlet, which will ensure a drainage route for water entering the ditch and so help to keep a constant water level in it.

The spray nozzles are now turned on and, when the water table is steady, the manometers can be read to enable a profile of the water table to be plotted. It is important when plotting this profile to relate it accurately to the position of the ring and other ground features. The water filled ditch surrounding the island serves to isolate its ground water conditions from effects outside.

In the second part of this experiment, the spray nozzles are stopped and water is withdrawn from the central well drain control valve.

A compensating flow must be introduced as a ground water supply to produce a steady water table elevation. To do this, connect the flexible tubing from the 3 l/min flow valve to the self-sealing connection on one of the French drains and slowly introduce the water supply until steady conditions are attained. The well discharge ought to be less than the rate of rain recharge falling on the central island in the first part of the experiment, and the correct value can be selected only by trial-and-error.

When the water table profile has been determined and plotted, the sprays should be turned on again to their previous setting and the combined effect of surface recharge and central well abstraction determined. The water table under these combined effects should reach a maximum height at some radius less than that of the "island". This maximum marks the water divide for ground water flow, rain falling inside this radius flowing to the well and outside to the "sea". When an island is set in a salt sea it is obviously very important that this water divide exists or salt water will be drawn through the soil to feed the well.

If the principle of superposition applies, the combined water table profile can be predicted by 'adding' the water tables determined previously under each separate ground water flow.

Results

Rainfall Flow Rate: ______ l/min

Ground Water Inflow Rate: ______ l/min

Tapping position **m**	**Manometer reading** **(rainfall only)** **m**	**Manometer reading** **(groundwater only)** **m**	**Manometer reading** **(rainfall only + groundwater only)** **m**	**Manometer reading** **(rainfall and groundwater)** **m**

Conclusion

Did the results suggest that the method of superposition is applicable to this simulation? What can be learned from the model that can be usefully applied to real-world situations?

Exercise K - Ground water flow between two canals with and without rainfall

Theory

When two neighbouring canals have their water surfaces maintained at different levels, there will be a flow of ground water between them from the higher to the lower. If, at the same time, there is surface recharge by rainfall, a water divide may form in the intervening water table and this means that a small proportion of the recharge is entering the upper canal and the larger part the lower canal.

It is suggested that students read the theory of superposition described in Exercise I before proceeding with this experiment.

Procedure

Form the two canals by excavating two trenches across the catchment tank, one near each end. Build up the intervening ground with the sand excavated from the canals. Connect the flexible tubing from the 3 l/min flow meter to the French drain on the same side as the highest of the two canals and turn on the water supply. This will establish the ground water flow without recharge and the correct flow can be found by experiment.

Connect the flexible tubing from the 5 l/min flow meter to the self-sealing connection for the spray nozzles. When the water table has been determined, turn on the spray nozzles until the water table between the two canals is elevated above the water level within the canals. It will be necessary to adjust the rainfall flow rate and the valves for the two French drains in order to achieve a constant level in the two canals. This is another experiment in which the principle of superposition can be tested by allowing the water surfaces in both canals to equalise while the rain is falling. This can be done by careful regulation of the appropriate valves.

Results

Tapping position **m**	**Manometer reading** **(rainfall only)** **m**	**Manometer reading** **(groundwater only)** **m**	**Manometer reading** **(rainfall only + groundwater only)** **m**	**Manometer reading** **(rainfall and groundwater)** **m**

Conclusion

Did the experiment suggest that the theory of superposition is applicable to this simulation? How might simulations of this type be applied to civil engineering projects such as canal construction?

Contact Details for Further Information

Main Office: **Armfield Limited**

Bridge House
West Street
Ringwood
Hampshire
England BH24 1DY

Tel: +44 (0)1425 478781
Fax: +44 (0)1425 470916
Email: sales@armfield.co.uk
support@armfield.co.uk
Web: http://www.armfield.co.uk

US Office: **Armfield Inc.**

9 Trenton - Lakewood Road
Clarksburg, NJ 08510

Tel/Fax: (609) 208 2800
Email: info@armfieldinc.com