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ENGINEERING TRIPOS PART IIA 2003
PAPER 3D6 ENVIRONMENTAL ENGINEERING II
SOLUTIONS

1. All possible solutions are included in this question, so a full mark would be awarded is 50% of the material is given in the solution.

(a) **Effects on infrastructure:**

Av. Annual Rainfall increases in UK by 2080s: varies across UK, more increase in N and W; S England and Wales, up to +9%; N England & Scotland, up to +17%. But extremes increase much more: More frequent high intensity rainfall events: +25% peaks in winter; -10% min drought flows in summer.

Hydraulic effects:

Examples of predictions of increased impact in runoff:

Severn Trent region: 4 test networks using 2yr 90 min rainfall event, 2080

- flood volume increases: 80% to 140%

Montgomery Watson Harza analysis (for Scotland): larger rainfall events:

- by 2080: 194% increase in such events per year

River flows become more extreme...Flooding increases

Increasing cost of insurance claims due to weather changes

Pollution effects

- heavier rains remove more nitrate and other chemicals from agricultural land
- chemicals driven into groundwater too
- solids erosion and deposition in floods
- health risk if sewage mixed with floodwater

General impact – Summer:

- Pollution in rivers: Low river flows, more polluted surface runoff
- Increase in CSO spill frequency and volumes
- Higher Pipe Surcharge frequency - Sewer structure deterioration

General impact - Winter

- increased infiltration into groundwater - longer wet periods - raised groundwater levels
- increased treatment flows - energy costs and process impact

Summary of impact of run-off increases – on drainage and river infrastructure

- Impact much greater than just proportional to rainfall increase; it's a 'double whammy' - systems are already 'on the edge' from continuing development and 'paving the countryside' pressures
- So allowing a small rainfall increase can result in the need for major new build projects

What can be done:

Mitigating climate change – reducing the cause...fossil energy use

- Use less energy by employing efficiency policies
- Use of renewable energy alternatives - little or no CO_2 emissions;
- **replace fossil fuels in electricity generation and transport uses**

Solutions - mitigating extra run-off and pollution

Land use and river changes to create less flooding from same rainfall - egs:

- Changing land use along streams, to reduce at source: - stock fencing, buffer strips, contour ploughing & land cover
- Altering stream channels - riffle / pool sequences, revetments, groynes, channel narrowing and variation - Increase in flow and depth

Solutions - designing to accommodate the rainfall change - but how much?

Design for projected run-off levels: Bigger pipes; Underground storage – but all more expensive.

Problem of uncertainty in design and cost – the range of uncertainty increases as you move from direct climate change impacts (temperature) to indirect ones (flooding, droughts):

Eg: Run -off equation: Run-off rate = Area x Coefficient x Rainfall Intensity

- In the run-off equation, only the Area is 'fact'...and even there we have to predict 'how much future development?'
- The run-off Coefficient is an estimate, varying perhaps +/- 20% due to antecedent conditions

- The Rainfall Intensity has a statistical relationship to frequency of occurrence, and we have to decide 'how often can we flood?'
- NOW - climate change uncertainty means that the whole 'I' prediction curve is itself uncertain too

Solutions - engineering – remember that the capacity of the existing 'hole in the ground' is fixed: first choice must be for solutions generally above ground and not more storage and bigger pipes. Reduce floods by:
- reduced flow rate and volume into drains, by 'retro-fitted' Sustainable Urban Drainage Systems
- Reuse of greywater from houses

Allow 'overland flow', managed flooding; needs better integrated planning
Use Sustainable Urban Drainage Solutions (SUDS) - Managing the flow rate of water through a drainage system using natural resources – wetlands, ponding, infiltration beds, swales, porous paving, etc; Upstream solution - not 'end of pipe'; tackling cause rather than treating effect; Multi-objectives – Drainage, Amenity, Wildlife, Storage, More research. [30%]

(b) (i) Typical Urban Drainage Catchment – information is needed on:
Pipe network, sizes, levels, and roughness, to define sewer system hydraulics. The network may comprise:
- 'combined' sewers - older systems mixing foul sewage and run-off from rainfall in one pipe system
- 'separate' - two separate pipe systems, one for each
- discharge pipes into 'Receiving Waters' - sea or river

Ancillary drainage and treatment structures – need size, volumes, storage, pump capacities, hydraulic capacities, treatment capabilities, interaction with receiving water levels:
- Combined Sewer Overflows (CSO), where excess rainfall ('storm') flows from combined systems discharge to receiving waters
- Pumping Stations/Overflows
- Sewage Treatment Works

Data needed for modeling includes:
- 'Dry weather flow' components – foul sewage flow, pollution loads per capita; industrial discharge loads and flows
- Contributing areas (for run-off), populations, runoff parameters
- Rainfall/runoff
- Surface washoff
- Industrial and domestic pollutant sources data
- Pollutant and sediment transport criteria. [15%]

(ii) Channel dimensions, gradient, roughness; Boundary conditions, flow, quality; Inputs from Urban Drainage System; Dispersion coefficients; Pollutant decay rates; Water quality processes (Dissolved Oxygen); Flow routing; Pollutant transport; Pollutant dispersion; Water quality processes.
Detailed River Model - Data Requirements
1. Asset Data - River cross and long sections, weirs
2. Flow/level Data - Flow data plus level data
3. Advection Dispersion Data - Dye tracer profiling
4. Water Quality Data Sonde - Dissolved Oxygen; Temperature; pH; (Ammonia)
5. Water Quality Auto Samplers - BOD; Suspended Solids; Nitrate; Ammonia [15%]

(iii) Sewer System to River or Sea: Urban drainage model component calculates a continuous sequence of flows, and corresponding concentrations of pollutants for a series of 'events' – dry weather days over a daily cycle of sewage discharge, and days of rainfall – for various rainfall hydrographs with a range of frequencies. These are used as inputs into the river (or sea) model.
Urban Drainage System to Wastewater Treatment Works:Urban drainage model component calculates a continuous sequence of flows, and corresponding concentrations of pollutants for a series of 'events' – dry weather days over a daily cycle of sewage discharge, and days of rainfall – for various rainfall hydrographs with a range of frequencies. These are used as inputs into the model for the sewage treatment plant (which is a sub-set of the Urban drainage model).

Wastewater Treatment Works to River or Sea: The sewage treatment plant process and hydraulic model, a sub-set of the Urban Drainage Model, calculates the modified flows and 'effluent' (after treatment) residual pollutant concentrations. These are used as inputs into the river (or sea) model. [15%]

(c) Switch away from 'archetypal' engineering responses:
- Visible, heavy engineering approaches
- End of pipe treatment at specific locations - treat what arrives, dilute and disperse
- Tendency to 'protection' of social assets e.g. via dredging
- 'Single issue' environmental treatment
- Absence of systems thinking or awareness of catchment approaches
- [new] Environmental problems following 'environmental' programmes…

A more holistic approach to catchment planning: [DEFRA - ICE 'Learning to live with Rivers': Oct 2001] said:
- design for whole catchments, not piecemeal
- improve communication with public; flooding 'odds', not 'return periods'
- extend cost benefit analysis to include social damage costs, to protect poorest
- Allow rivers to revert to flood natural flood plains - but some properties suffer.

Learn to implement the complex solutions that sustainability needs - make better engineering choices – less purely technical 'end of pipe' solutions; more 'Social + Technical' solutions - change in upstream land uses; SUDS implementation;

Improve our ability to handle Technical Complexity: Geographical Information Systems, data handling and modeling to deal with geography, physics, and chemistry - and with the complexities of biology. Learn to handle Social Complexity: to engage with the community (politics & public, housing design and pressures, town planners, developers and insurers) and develop the capability to consult, facilitate and agree on the complex solutions needed – all these players have mixed responsibilities which interact, and we need negotiation on who pays.

Integrated modeling approach: use a holistic (catchment wide) approach to problem identification and development of solutions. Understand complex rainfall, runoff, fluvial and water quality processes - through modeling. Solve problems of data availability, quality, and costs; and improve software to reduce computer simulation run times. Target investment to deliver cost-effective and sustainable solutions; minimise new construction wherever possible.

Learn a different focus for engineering skills – eg. in SUDS design:
- Field based design - needs local consultation and iteration
- Needs personal interface with urban space and community - Multi-disciplinary, multi-professional approach
- High-tech processes used in design, not in the built project itself - Uses simple but technically clever products and local construction skills - favours SMEs and market competition
- Plan for maintenance. [25%]

A1

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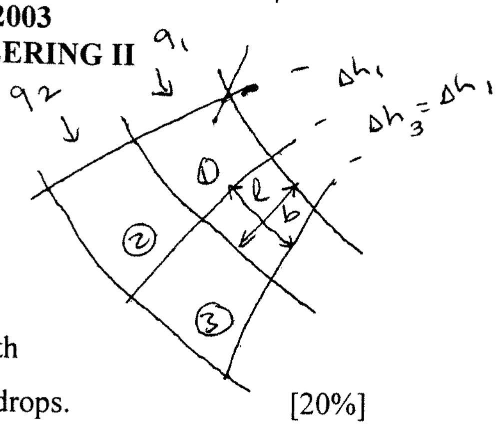


2. (a) Darcy's law: $v = ki$

$q_1 = A_1\ v_1 = b_1\ v_1 = b_1\ k\ \Delta h_1/l_1$

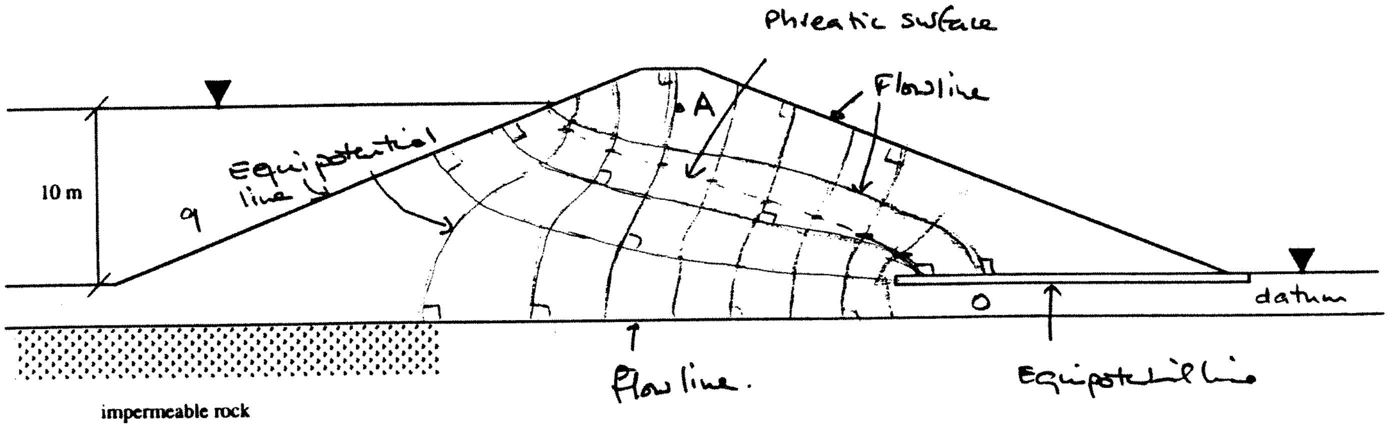
$q_2 = q_3$, same flow channel

and if $b/l = 1$ then $q_1 = q_2$, same Δh,

Hence for 'square flownet' $q = N_f\, k\, \Delta h = H\, k\, N_f/\ N_d$ /m length

Where N_f = no. of flow channels and N_d = no. of equipotential drops. [20%]

(b) (i) The upstream surface of the embankment and the drainage layer are equipotential lines. The interface between the embankment and impermeable rock surface is a flow line. As the embankment is fully saturated, the top of the embankment and downstream slope is also a flow line. A typical flownet is as shown below:



[40%]

(ii) The leakage rate is

$$= H\,k\,N_f/N_d$$
$$= 10 \times 3 \times 10^{-8} \times (4/9)$$
$$= 1.33 \times 10^{-7}\ m^3/s$$

[10%]

(iii) The phreatic surface is drawn using the dotted line on the Figure above, by plotting the line on which the elevation is equal to the potential, since the pore pressure is zero. [20%]

(iv) The potential at point A is (6/9) x10 = 6.66m.
Pressure head = potential – elevation head = 6.66 – 10 = -3.33m
Pore pressure = - 33.3kPa. [10%]

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3. (a) Assume unit length into the page. Continuity of mass flow rate requires that the volumetric flow rate of water through layer 1 be the same as that through payer 2. Darcy's law for layer 1 gives:

$v = Q/W = K_1 \Delta h_1/L_1$, therefore $\Delta h_1 = v L_1/K_1$

where Δh_1 is the potential head difference across the top and bottom of layer 1. Similarly for layer 2: $\Delta h_2 = v L_2/K_2$

Therefore:

$$\Delta h_1 + \Delta h_2 = v\left[\frac{L_1}{K_1} + \frac{L_2}{K_2}\right]$$

Rearranging gives

$$v = \frac{1}{\left(\frac{L_1}{K_1} + \frac{L_2}{K_2}\right)}(\Delta h_1 + \Delta h_2) \quad or \quad v = \frac{L_1 + L_2}{\left(\frac{L_1}{K_1} + \frac{L_2}{K_2}\right)}\left(\frac{\Delta h_1 + \Delta h_2}{L_1 + L_2}\right)$$

and since $\frac{\Delta h_1 + \Delta h_2}{L_1 + L_2}$ *is the effective vertical hydraulic gradient aross the whole deposit then*

$$K_v = \frac{L_1 + L_2}{\left(\frac{L_1}{K_1} + \frac{L_2}{K_2}\right)}$$

[25%]

(b) (i) $L_1 = 2$m, $L_2 = 6$m, $K_1 = 0.8 \times 10^{-5}$m/s and $K_2 = 0.3 \times 10^{-7}$m/s hence $K = 4 \times 10^{-8}$m/s. [10%]

(ii) From (i) and part (a) above $v = 4 \times 10^{-8} \times (5.5/8) = 2.75 \times 10^{-8}$ m/s.
Hence $v_f = 2.75 \times 10^{-8}/0.45 = 6.11 \times 10^{-8}$ m/s.
$z = 3$m, $v_f = 6.11 \times 10^{-8}$ m/s, $D_d = 2 \times 10^{-9}$ m²/s, $\tau = 0.4$, $\alpha = 0.4$m, $c/c_o = 0.0000$
$D_\ell = D_d^* + v_f \alpha = 0.8 \times 10^{-9} + 6.11 \times 10^{-8} \times 0.4 = 2.52 \times 10^{-8}$ m²/s

Again $c/c_o = 0$ means $\beta = 3$, so

$(8 - 6.11 \times 10^{-8}\, t)^2 = 9\,(4 \times 2.52 \times 10^{-8}\, t)$

$64 - 9.78 \times 10^{-7}\, t + 3.33 \times 10^{-15}\, t^2 = 9.07 \times 10^{-7}\, t$

$3.73 \times 10^{-15}\, t^2 - 1.89 \times 10^{-6}\, t + 64 = 0$

Hence $t = \dfrac{1.89 \times 10^{-6} \pm 1.618 \times 10^{-6}}{2 \times 3.73 \times 10^{-15}}$

t = 36487936 secs = 1.16 years (lower of the two solutions). [30%]

(iii) Advective flow only will take $8 / 6.11 \times 10^{-8} = 4.15$ years. [20%]

(iv) Comparing the results from (b) and (c) clearly shows that when advection is accompanied with dispersion that the spread of the contaminants ahead of the average advective flow could be much increased. [15%]

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4. (a) Sorption: Sorption is the mechanism which removes contaminants from solution. Two types exist: adsorption and absoprtion. Adsorption is when a solute accumulates on the surface of the grains and absorption is when the solute is sucked into the inside of the grains. Adsorption is the most common of the two and is a surface reaction of particular importance in clay minerals. Because of their negative surface change, ion exchange can occur by which ions are selectively adsorbed onto the surface of clay particles. Adsorption can be linear and can also be high affinity. The classical advection-dispersion equation uses the linear adsorption model for its simplicity. [20%]

(b) Functions of landfill cover systems:

(i) to control water infiltration into the landfill,
(ii) to control gas emissions
(iii) to resist erosion of the waste
(iv) to protect the public from contact with the waste
(v) to minimise odours
(vi) to give a better appearance e.g. use vegatation. [20%]

(c) Immobilisation or stabilisation/solidification (S/S) is to physical and chemical encapsulation of contaminants within a matrix, usually cementitious material based. Hence the process does not remove the contaminants but reduces their impact on the environment by preventing their further spreading. Binders include cement in combination with some of the following: pfa, lime, clays. S/S is best suited to inorganic waste and especially heavy metals. S/S or organics has been problematic but special binders have been developed. The process can be carried out *in situ* or ex-situ. S/S is used to treat wastes as well as contaminated soils and is likely to be the most common pretreatment of waste prior to landfilling (Landfill Directive). May advantages: fast, uses conventional technique, cost effective. Main disadvatnages; does not remove contaminants. [20%]

(d) Electro-kinetic remediation: a D.C. electric field is applied causing ions to migrate according to their electric charge; water also migrates. Electro-kinetic has the potential for clean-up of low hydraulic conductivity soils contaminated with heavy metals. Advantages: contaminants are removed from the soil, uses familiar technology, flexible to suit site and problem, can contain the contaminants during clean-up. Disadvantages: expensive and long term, inefficient as clean water is also extracted, surface treatment necessary. [20%]

(e) Hydraulic measures are used to control the movement of groundwater within a site as part of a clean-up scheme. By changing the hydrological regime it is possible to control and prevent a contaminant plume reaching a sensitive target, and to maintain water levels at required values within and external to a barrier system. Hydraulic measures are closely related to pump and treat clean-up methods. Advantages: familiar techniques and procedures, flexible as additional wells can be added. Disadvantages: duration of pumping and long-term performance is uncertain, contaminants extracted need to be treated, pumping may affect nearby buildings, expensive and monitoring is essential. [20%]