Surname		Other Names	
Centre Number		Candidate Number	
Candidate Signature			

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General Certificate of Education
June 2004
Advanced Level Examination

ASSESSMENT and QUALIFICATIONS ALLIANCE

ENVIRONMENTAL SCIENCE ESC7
Unit 7 Alternative to Practical Investigation

Wednesday 30 June 2004 1.30 pm to 3.30 pm

No additional materials are required.
You may use a calculator.

Time allowed: 2 hours

Instructions
- Use blue or black ink or ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions in the spaces provided.
- Do all rough work in this book. Cross through any work you do not want marked.

Information
- The maximum mark for this paper is 75.
- Mark allocations are shown in brackets.
- You are expected to use a calculator where appropriate.
- You will be assessed on your ability to use an appropriate form and style of writing, to organise relevant information clearly and coherently, and to use specialist vocabulary, where appropriate.
- The degree of legibility of your handwriting and the level of accuracy of your spelling, punctuation and grammar will also be taken into account.
- This unit assesses your understanding of the relationship between the different aspects of Environmental Science.

For Examiner's Use			
Number	Mark	Number	Mark
1			
2			
3			
4			
Total (Column 1) →			
Total (Column 2) →			
TOTAL			
Examiner's Initials			

AN INVESTIGATION INTO THE WATER QUALITY OF A RIVER

A group of Advanced Level Environmental Science students decided to investigate the water quality of a local river following reports from fishermen that fewer fish were being caught than in previous years. The students decided to survey a 50 km stretch of the river which is a tributary of a large river that flows through the West of England.

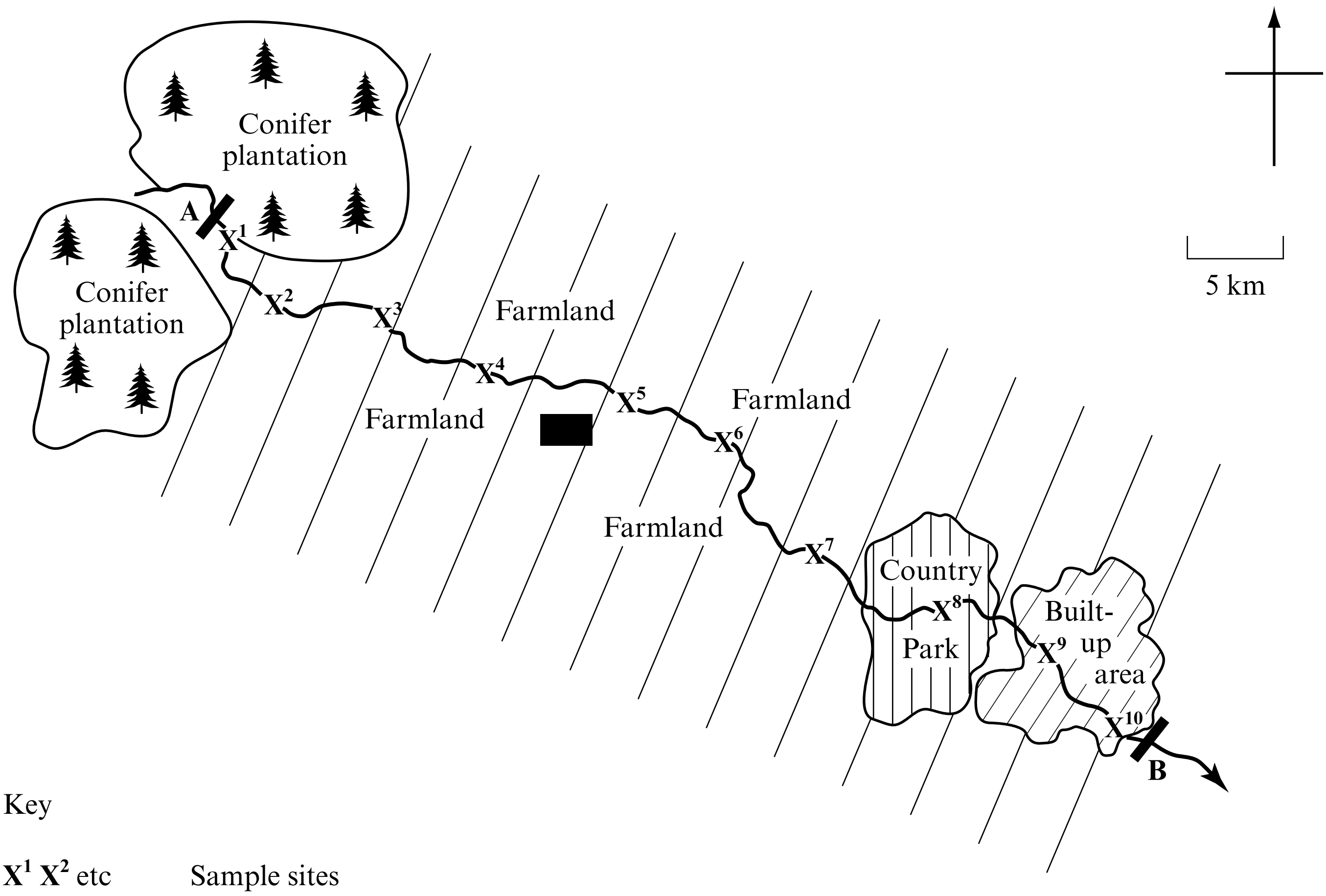
The upstream section of the river flows through a conifer plantation. It then meanders through farmland where the fields adjacent to the river are principally used for arable cropping and cattle grazing. One farm in the area has a large intensive pig-rearing unit. Downstream the river flows towards a small town on the outskirts of which is a Country Park where fishing is permitted.

Aim

The students decided to sample 10 sites along the river in order to assess water quality by assessing:

- chemical variables — dissolved oxygen, Biochemical Oxygen Demand (BOD), ammonia and pH;
- plant nutrients — nitrate and phosphate;
- aquatic life — macro-invertebrate populations.

The sketch map shows the main land uses surrounding the stretch of the river under investigation.



Key

X^1 X^2 etc	Sample sites
A — B	50 km stretch of the river surveyed
■	Site of intensive pig-rearing unit

Background Information

There are many pressures on inland watercourses. They are used for the abstraction of water for public supply, agriculture and industry, for the disposal of *treated* domestic sewage, farm effluents and industrial wastes, and, increasingly, for leisure activities as they also have a high amenity value. Inland waterways should therefore be as clean and litter-free as possible, both to meet the quality needed for those varied uses, and to support fish and other aquatic life.

Water quality can be influenced by many factors. It can be affected directly by discharges from farms, industrial installations and sewage works, or from pollution events such as spillages. Water can also be affected indirectly: from run-off from roads, industrial sites or land when the water may have picked up contaminants on the way, from leaching of contaminants from rocks, soils or the storage of hazardous chemicals and from the deposition of airborne pollutants such as acid rain. The surrounding vegetation and soil type can also influence water quality.

Water Quality Standards

(a) Chemical quality

The Environment Agency carries out regular monitoring of all rivers and canals in England and Wales. The Agency's method for classifying the chemical water quality of rivers and canals is known as the General Quality Assessment scheme (GQA). The scheme allocates one of six grades (A to F) to each stretch of river using the same procedures throughout England and Wales. The grade, as shown in **Table 1**, is defined by standards for dissolved oxygen, Biochemical Oxygen Demand (BOD) and ammonia as these are indicators of pollution from farms or from sewage works.

GQA grade	Dissolved oxygen/ minimum % saturation	Biochemical Oxygen Demand/maximum mg l^{-1}	Ammonia/ maximum mgN l^{-1}
A	80	2.5	0.25
B	70	4.0	0.6
C	60	6.0	1.3
D	50	8.0	2.5
E	20	15.0	9.0
F	<20	>15.0	>9.0

Table 1 Standards for the chemical GQA

(b) Biological surveys

To provide further information about the health of a river, a biological assessment is carried out alongside the chemical testing. This is based on the monitoring of the small animals that live in or on the bed of the river (the macro-invertebrates). The number and diversity of freshwater species found in samples can be used to make inferences about water quality.

Turn over ►

Table 2 describes the general characteristics of each grade of river water, together with the indicators of biological quality.

Grade	Description	Likely uses and characteristics	Biological indicators
A	Very good	All abstractions Very good salmonid (salmon and trout) fisheries Cyprinid* fisheries Natural ecosystems	Biology similar to that expected for an unpolluted river. High diversity of groups, usually with several species of any one group.
B	Good	All abstractions Salmonid fisheries Cyprinid fisheries Ecosystems at, or close to, natural	Biology is a little short of that expected for an unpolluted river. Small reduction in the number of groups that are sensitive to pollution. Small increase in the number of individuals of groups that tolerate pollution.
C	Fairly good	Potable supply after advanced treatment Other abstractions Good cyprinid fisheries Natural ecosystems corresponding to good cyprinid fisheries	Biology worse than that expected for an unpolluted river. Many sensitive groups absent, or numbers of individuals reduced. Marked rise in numbers of individuals of groups that tolerate pollution.
D	Fair	Potable supply after advanced treatment Other abstractions Fair cyprinid fisheries Impacted ecosystems	Sensitive groups scarce and contain only small numbers of individuals. A range of pollution-tolerant groups present, some with high numbers of individuals.
E	Poor	Low grade abstraction for industry Fish absent or sporadically present, vulnerable to pollution Impoverished ecosystems	Biology restricted to pollution tolerant species with some groups dominant in terms of the numbers of individuals. Sensitive groups rare or absent.
F	Bad	Very polluted rivers which may cause nuisance Severely restricted ecosystems	Biology limited to a small number of very tolerant groups such as worms, midge larvae, leeches and water hoglouse, present in very high numbers. In the worst case there may be no life present.

*Cyprinids are the dominant family of freshwater fish in most parts of the world. The family includes roach, tench, chub, rudd, bream, carp and minnow.

Table 2 Grades of river quality and biological indicators

(c) **Nutrient grades for river water**

A grade of 1 to 6 is allocated to both phosphate and nitrate content; however, these are not linked into a combined nutrients grade. In this respect this differs from the chemical and biological assessment which combine variables into a single grade. This cannot be done for nutrients as there are no set "good" or "bad" concentrations for nutrients in rivers. "Very low" nutrient concentrations, for example, are not necessarily good or bad; the classifications merely compare the concentrations in one river with another.

Tables 3 and **4** give the limits for each grade for phosphates and nitrates.

Classification for phosphate Grade	Grade limit / minimum mgP l^{-1} Average	Description
1	<0.02	Very low
2	0.02	Low
3	0.06	Moderate
4	0.1	High
5	0.2	Very high
6	>1.0	Excessively high

Table 3 Phosphate grades

High concentrations of phosphates are indicative of possible existing or future problems of eutrophication. High concentrations do not necessarily mean that the river is polluted. Other factors have to be taken into account such as the amount and type of algae present, flow rates and dissolved oxygen content.

Classification for nitrate Grade	Grade limit / minimum mgNO_3 l^{-1} Average	Description
1	<5	Very low
2	5	Low
3	10	Moderately low
4	20	Moderate
5	30	High
6	>40	Very high

Table 4 Nitrate grades

The EC Drinking Water Directive and the EC Nitrate Directive set limits for nitrate levels of 50 mg per litre.

Source for all tables: Environment Agency website: *www.environment-agency.gov.uk. Information researched by WWF Data Support for Education.*

TURN OVER FOR QUESTION ONE

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*This investigation is in **two** sections.*
***Section A** is in **three** parts and tests the skills of planning, implementing, analysing and drawing conclusions.*
***Section B** tests the ability to discuss the findings and evaluate the whole investigation.*

SECTION A

Answer **all** questions in the spaces provided.

1 Chemical tests

Water tests were taken at 10 points spaced at 5 km intervals along the stretch of the river shown in the map. Some of the tests were carried out on site but for other tests water samples were taken back to the laboratory. Tests were carried out to determine dissolved oxygen content, Biochemical Oxygen Demand (BOD), ammonia content and pH. The sampling procedure was repeated three times during the autumn at weekly intervals and the results averaged.

(a) (i) Suggest precautions that the students should have taken in the water sampling procedure in order to ensure fair testing.

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(5 marks)

(ii) Suggest precautions that would be necessary to ensure personal safety when carrying out water sampling in a river.

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(3 marks)

(b) Describe a method that could be used for measuring:

(i) dissolved oxygen content;

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(2 marks)

(ii) Biochemical Oxygen Demand (BOD).

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(4 marks)

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The results of the various tests are shown in **Table 5**.

	Sample site									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Dissolved oxygen / % saturation	83	80	79	56	38	42	52	58	62	65
Biochemical Oxygen Demand /mg l^{-1}	0.8	1.2	1.6	2.0	12.4	11.6	8.0	5.9	4.8	4.2
Total ammonia / mgN l^{-1}	0.2	0.3	0.6	7.5	9.4	6.9	4.0	2.5	2.4	2.1
pH	5.3	6.1	6.5	7.1	7.3	7.1	7.2	7.6	7.9	7.4

Table 5 Results of chemical tests (mean values)

(c) Plot a graph to show variations in the levels of dissolved oxygen and BOD.

(4 marks)

18

NO QUESTIONS APPEAR ON THIS PAGE

TURN OVER FOR THE NEXT QUESTION

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2 Plant nutrients and turbidity

One student noticed that the water flowing through farmland was more turbid than that further upstream. The land adjacent to the river at this site was improved grassland used for grazing and a silage crop to which fertilisers were applied in the autumn. The students decided to investigate nitrate and phosphate levels and to assess turbidity in further detail.

Tests to measure the nitrate and phosphate content of the river water were made at each of the test sites. The results are shown in **Table 6**.

Test site	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Phosphate concentration / mgP l^{-1}	0.02	0.02	0.09	0.15	0.20	0.17	0.09	0.06	0.04	0.02
Nitrate concentration / $mgNO_3\ l^{-1}$	5.00	5.50	16.10	22.00	31.00	25.00	22.50	15.70	9.50	5.80

Table 6 Nitrate and phosphate concentrations

Water samples were tested for turbidity by measuring the amount of suspended sediment weekly for a period of two months during the autumn at the site where the river ran through the improved grassland **(Site 3)**. As there had been some unexpected periods of heavy rainfall, the student also decided to investigate the amount of storm run off from the agricultural land. The results are shown in **Table 7**.

Week Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Suspended sediment / mg l^{-1}	32	29	35	59	45	48	40	45
Run-off / mm	33	39	45	64	55	50	38	60

Table 7 Suspended sediment and run-off values at site 3 over an 8 week period

(a) Use an appropriate graphical technique to illustrate whether there is any relationship between the amount of suspended sediment in the water and the run-off during the test period.

(4 marks)

(b) State an appropriate hypothesis suggested by the data shown in **Table 7** and the graph.

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(1 mark)

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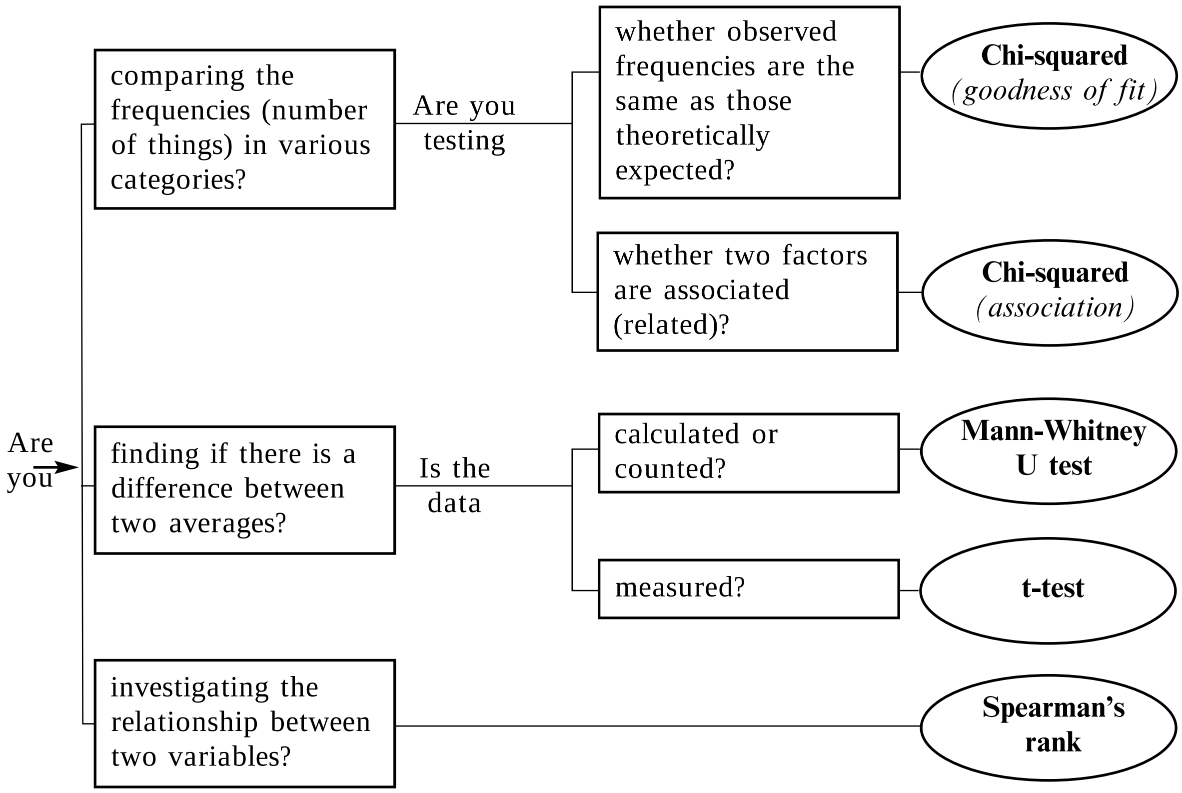
(c)



(i) Use the flow diagram to choose an appropriate statistical technique to test your hypothesis. Give **two** reasons to justify your choice of test.

Choice of test ....

1. ....

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2. ....

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(3 marks)

(ii) Carry out your chosen test using the data from **Table 7** and the formulae and tables in the Appendix. State your conclusions clearly.

Show your working.

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(7 marks)

(iii) The critical value used for many statistical tests is often at the $p = 0.05$ level. Explain the meaning of this level of significance.

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(1 mark)

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3 Biological sampling

Water quality can also be assessed by sampling the macro-invertebrates (small animals that can be seen with the naked eye) found in kick-samples. The range of species found can be compared with the range that would be expected if the river was not polluted or physically damaged.

(a) Describe how the technique of kick-sampling would be carried out in this survey.

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(b) The students decided to use the results of their kick-sampling to calculate a diversity index for each stretch of the river.

The invertebrates found in the sample from **Site 6** are shown in **Table 8**.

Invertebrate group (common names)	**Number in sample**
Tubifex worms	12
Midge larva species a	23
Midge larva species b	9
Water hoglouse	6
Freshwater shrimps	2
Leeches	4

Table 8 Results of a kick sample from Site 6

(i) Calculate Simpson's Diversity Index for **Site 6** using the formula:

$$\mathbf{D} = \frac{\mathbf{N(N-1)}}{\sum \mathbf{n(n-1)}}$$

where **D** = the diversity index
N = the total number of individuals of all species
n = the number of individuals of each species
Σ = the sum of

Show your working.

Answer ....
(3 marks)

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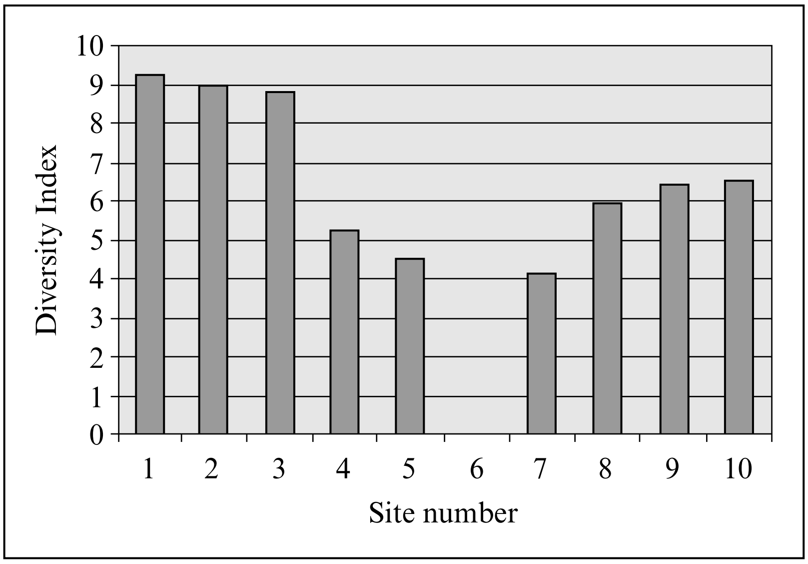
(ii) Simpson's Diversity Index was calculated for each site along the river. The results are shown in the graph:



Insert your calculated value for **Site 6** in the graph. *(1 mark)*

(iii) Explain why calculating an index of diversity is preferable to counting the number of different species present.

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(2 marks)

(c) (i) Suggest **one** further group of organisms, excluding fish, that could be sampled as indicators of water quality.

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(1 mark)

(ii) Describe an appropriate technique that could be used to sample this group of organisms.

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(2 marks)

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SECTION B

Answer **all** parts of the question in the spaces provided.

In order to gain credit in this section your answer should be written in continuous prose and expressed logically and in clear scientific terms.

4 (a) Using information in the background section and with reference to the investigations carried out, discuss the effect of the land uses on the water quality of the river.

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(b) Discuss any factors relating to the methods used that might affect the reliability of the results obtained.

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(5 marks)

(c) Suggest how you might modify or extend the study on the effect of different land uses on river water quality.

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(4 marks)

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(d) Suggest how the Environment Agency might use information on water quality to benefit the fishermen using the river.

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(4 marks)

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END OF QUESTIONS

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APPENDIX

Statistical formulae and tables

1 Mean

$$\bar{x} = \frac{\sum x}{n}$$

where:
$\bar{x}$ = mean
x = the individual measurements
n = total number of measurements
$\sum$ = the sum of

2 Standard deviation(s)

$$s = \sqrt{\frac{\sum(x - \bar{x})^2}{n - 1}}$$

3 Chi-squared (χ^2) test

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

where:
$\sum$ = the sum of
O = the observed value
E = the expected value

Critical Values for the Chi-Square (χ^2) Test

Degrees of Freedom (df)	**Level of significance (*P*)**				
	0.05	0.025	0.01	0.005	0.001
1	3.84	5.02	6.63	7.88	10.83
2	5.99	7.38	9.21	10.60	13.81
3	7.81	9.35	11.34	12.84	16.27
4	9.49	11.14	13.28	14.86	18.47
5	11.07	12.83	15.09	16.75	20.52
6	12.59	14.45	16.81	18.55	22.46
7	14.07	16.01	18.48	20.28	24.32
8	15.51	17.53	20.09	21.96	26.13
9	16.92	19.02	21.67	23.59	27.88
10	18.31	20.48	23.21	25.19	29.59
11	19.68	21.92	24.73	26.76	31.26
12	21.03	23.34	26.22	28.30	32.91
13	22.36	24.74	27.69	29.82	34.53
14	23.68	26.12	29.14	31.32	36.12

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4 Mann-Whitney U Test

$$U = n_1 n_2 + \frac{n_1(n_1 + 1)}{2} - R_1$$

$$U' = n_1 n_2 + \frac{n_2(n_2 + 1)}{2} - R_2$$

where:

R_1 = sum of the ranks of sample 1
R_2 = sum of the ranks of sample 2
n_1 = size of the smaller sample
n_2 = size of the larger sample

Critical values for the Mann-Whitney U test (at the p = 0.05 level). If the smallest U value is less than or equal to the critical value then there is a significant difference between the two sets of data.

Values of n_1 \ Values of n_2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1																				
2								0	0	0	0	1	1	1	1	1	2	2	2	2
3					0	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8
4				0	1	2	3	4	4	5	6	7	8	9	10	11	11	12	13	13
5			0	1	2	3	5	6	7	8	9	11	12	13	14	15	17	18	19	20
6			1	2	3	5	6	8	10	11	13	14	16	17	19	21	22	24	25	27
7			1	3	5	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34
8		0	2	4	6	8	10	13	15	17	19	22	24	26	29	31	34	36	38	41
9		0	2	4	7	10	12	15	17	20	23	26	28	31	34	37	39	42	45	48
10		0	3	5	8	11	14	17	20	23	26	29	33	36	39	42	45	48	52	55
11		0	3	6	9	13	16	19	23	26	30	33	37	40	44	47	51	55	58	62
12		1	4	7	11	14	18	22	26	29	33	37	41	45	49	53	57	61	65	69
13		1	4	8	12	16	20	24	28	33	37	41	45	50	54	59	63	67	72	76
14		1	5	9	13	17	22	26	31	36	40	45	50	55	59	64	67	74	78	83
15		1	5	10	14	19	24	29	34	39	44	49	54	59	64	70	75	80	85	90
16		1	6	11	15	21	26	31	37	42	47	53	59	64	70	75	81	86	92	98
17		2	6	11	17	22	28	34	39	45	51	57	63	67	75	81	87	93	99	105
18		2	7	12	18	24	30	36	42	48	55	61	67	74	80	86	93	99	106	112
19		2	7	13	19	25	32	38	45	52	58	65	72	78	85	92	99	106	113	119
20		2	8	13	20	27	34	41	48	55	62	69	76	83	90	98	105	112	119	127

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5 t-test

$$t = \frac{[\bar{x}_1 - \bar{x}_2]}{\sqrt{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)}} \qquad v = n_1 + n_2 - 2$$

where:

s = standard deviation (candidates should note that on some calculators the symbol σ may appear in place of the symbol s).

$\bar{x}$ = mean

n = sample size

v = degrees of freedom

Values of n_1

Degrees of freedom (df)	***p* values** 0.10	0.05	0.01	0.001
1	6.31	12.71	63.66	636.60
2	2.92	4.30	9.92	31.60
3	2.35	3.18	5.84	12.92
4	2.13	2.78	4.60	8.61
5	2.02	2.57	4.03	6.37
6	1.94	2.45	3.71	5.96
7	1.89	2.36	3.50	5.41
8	1.86	2.31	3.36	5.04
9	1.83	2.26	3.25	4.78
10	1.81	2.23	3.17	4.59
12	1.78	2.18	3.05	4.32
14	1.76	2.15	2.98	4.14
16	1.75	2.12	2.92	4.02
18	1.73	2.10	2.88	3.92
20	1.72	2.09	2.85	3.85
22	1.72	2.08	2.82	3.79
24	1.71	2.06	2.80	3.74
26	1.71	2.06	2.78	3.71
28	1.70	2.05	2.76	3.67
30	1.70	2.04	2.75	3.65
40	1.68	2.02	2.70	3.55
60	1.67	2.00	2.66	3.46
120	1.66	1.98	2.62	3.37
∝	1.64	1.96	2.58	3.29

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6 Spearman Rank Correlation Coefficient (r_s)

$$r_s = 1 - \frac{6 \sum D^2}{n(n^2 - 1)}$$

where:
$\sum$ = the sum of
D = the difference between each pair of ranks
n = sample size

Critical values for the Spearman Rank Correlation (r_s) (at the $p = 0.05$ level)

Number of pairs of measurements	**Critical value**
5	1.00
6	0.89
7	0.79
8	0.74
9	0.68
10	0.65
12	0.59
14	0.54
16	0.51
18	0.48
20	0.45
22	0.43
24	0.41
26	0.39
28	0.38
30	0.36

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