OFFICE OF PUBLIC WORKS
FLOOD STUDIES UPDATE PROGRAMME

WORK-PACKAGE WP-2.2
"FREQUENCY ANALYSIS"

APPENDIX 1

TREND ANALYSIS
ANNUAL MAXIMUM FLOWS IN IRISH RIVERS

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TREND ANALYSIS
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ABBRIVIATIONS

POT	Peaks Over Threshold
EDA	Exploratory Data Analysis
EV1	Extreme Value Type 1 Distribution
AM	Annual Maximum
CDF	Cumulative Distribution Function

1.0 Introduction

In flood frequency analysis a major assumption is that all observations in a data set are independent (random) and identically distributed. This study examines the validity of this assumption about the series of annual maximum floods of the Irish Rivers. Randomness cannot be proved but it can be disproved by the presence of some feature of a nonrandom nature, such as trend or serial persistence (positive serial correlation). Various statistical tests have been carried out for this purpose and the details of which are discussed in the following sections of this report.

2.0 Purpose of Trend Analysis

Detection of abrupt or gradual changes in hydrological records, and river discharge in particular, is of considerable scientific and practical importance, being fundamental for planning of future water resources and flood protection. Traditionally, design rules are based on the assumption of stationary hydrology, resulting in the principle that the past is the key to the future, which has a limited validity in the era of global change. If the stationarity assumption is not correct then the existing procedures for designing water-related structures: dams, dikes, etc. will have to be revised. Otherwise, systems, would be over or under-designed and might not serve their purpose adequately, or be over costly.

The changes in river flow can be caused directly by human activities such as urbanization, reservoir, drainage systems, water abstraction, land-use changes or by natural catchment changes (e.g. natural changes in channel morphology), climate variability and problems linked to data such as, instrumental error, change in measurement techniques, etc. However, climate is the most important driver of the hydrological cycle. Since the climate system and water cycle are intimately linked, any change in one of the systems induces a change in another. Change in a series can occur in numerous ways: e.g. gradually (a trend), abruptly (a step-change). It may affect the mean, median, variance, autocorrelation, or almost any other aspect of data.

The purpose of trend testing is to determine if the values of a random variable generally increase (or decrease) over some period of time in statistical terms (Helsel and Hirsch, 1992).

3.0 Trend Analysis Procedure

3.1 The main stages of a statistical analysis of change in hydrological data include: (Kundzewicz, 2004)

- Decide what type of series/variable to test depending on the issue of interest (e.g. monthly averages, annual maxima, Peaks Over Threshold (POT) series, etc.).
- Decide what type of change is of interest (gradual or step change).
- Check out data assumptions (e.g. use exploratory data analysis, or a formal test).
- Select a statistical test. This means selecting a test statistic and selecting a method for evaluating significance levels.
- Evaluate significance levels.
- Investigate and interpret results

3.2 Exploratory data analysis (EDA) is an advanced visual examination of the data and forms an integral part of any study of change. It involves using graphs to explore, understand and present data, and is an essential component of any statistical analysis. The first use of EDA is usually to examine the raw data in order to identify such features as data problems (outliers, gaps in the record, etc.); temporal patterns (e.g. trend or step-change, seasonality); and regional and spatial patterns. Exploratory data analysis also plays an important role in checking out test assumptions such as independence, or statistical distribution of data values. Common types of graph that can be useful for hydrological data series include histograms and normal probability plots, autocorrelation plots, scatter plots and smoothing curves. A well-conducted EDA is such a powerful tool that it can sometimes eliminate the need for a formal statistical analysis (Kundzewicz, 2004).

3.3 Any statistical test includes (i) naming a null hypothesis, (ii) naming a test statistic and its distribution under the null hypothesis, (iii) naming a critical region for the test statistic in which, under the null hypothesis, the value of the test statistic falls with probability α, (iv) computing the test statistic from a sample, and (v) rejecting the null hypothesis or not according to whether the observed test statistic value falls in the critical region.

The choice of a significance level (α) is completely arbitrary (Barnett, 1983, 1991; Casella and Berger, 1990; Fisher 1958) but the values $\alpha = 0.05$ and $\alpha = 0.01$ are the most frequently used and are also adopted in this report.

3.4 An alternative way to conclude a test of hypotheses is to compare the p-value of the sample test statistic with significance level (α). The p-value of the sample test statistic is the smallest level of significance for which we can reject Ho. In other words, the p-value of a statistical hypothesis test is the probability of getting a value of the test statistic as extreme as or more extreme than that observed by chance alone, if the null hypothesis H_0, is true. The p-value is compared with the actual significance level of our test and, if it is smaller, the result is significant. That is, if the null hypothesis were to be rejected at the 5% significance level, this would be reported as "$p<0.05$". The smaller it is, the more convincing is the rejection of the null hypothesis. It indicates the strength of evidence for rejecting the null hypothesis H_0, rather than simply concluding "Reject H_0" or "Do not reject H_0".

The p-value serves a valuable purpose in the evaluation and interpretation of research findings. It enables the researchers to set their own level of significance and to reject or accept the null hypothesis in accordance with their own criterion rather than that of fixed level of significance.

3.5 Statistical Tests Used in Trend Analysis

3.5.1 Statisticians have developed many test procedures for detecting any trend in hydrological time series. They are mainly classified as parametric and non-parametric. If any test does not depend on the form of parent distribution from which the sample is drawn, then the test is distribution free or non-parametric otherwise it is a parametric test. Non-parametric tests require few if any assumptions about the shapes of the underlying population distributions. Parametric tests make use of information consistent with interval scale measurement, whereas non-parametric tests typically make use of ordinal information only. The selection of a test to be used is sometimes difficult.

Non parametric tests are less powerful, because parametric tests use more of the information available in a set of numbers. Therefore, when the assumptions for a parametric test are met, it is preferable to use the parametric test rather than a non-parametric test. If the assumptions made in a statistical test are not fulfilled by the data, then test results can be meaningless, in the sense that the estimates of significance level would be grossly incorrect (Kundzewicz, 2004).

Hydrological data are often strongly non-normal and this means that tests which assume and underlying normal distribution are not adequate. In general, parametric tests are more powerful for a given n (record length) when the variable is normally distributed, but much less powerful when it is not, compared with the non-parametric tests (Hirsch et al., 1991). Distribution-free methods are recommended because they allow minimal assumptions to be made about the data and are therefore particularly suited to hydrological series, which are often neither normally distributed nor independent (Kundzewicz, 2004).

3.5.2 Based on the above and since it was found during the 1975-UK Flood Studies that the two-parameter Extreme Value type 1 (EV1 or Gumbel) distribution can adequately describe the Irish Annual Maximum Flood Series, the use of normality based parametric tests was not considered to be appropriate in this case. Non-parametric tests are used in order to test the underlying assumptions of independent and identically distributed time series. However, in order to compare the power of the tests, two parametric tests are also used.

3.5.3 The null hypothesis H_0 for the tests for trend is that there is no trend in the data. The null hypothesis H_0 for the tests for changes or difference in means/medians is that there are no changes or difference in the means/medians between two data periods. The null hypothesis H_0 for the tests for randomness (independence) is that the data come from a random process. It is considered that the alterative hypotheses for all tests are non-directional i.e. all tests are two tailed tests.

3.5.4 The following 6 tests were employed in detecting trends, shift and serial dependency in Annual Maximum Flood Series of Irish Rivers.

A) Tests for serial persistence or trend:

i) Mann-Kendall (non-parametric test for trend)
ii) Spearman's Rho (non-parametric test for trend)
iii) Mean-weighted Linear Regression test (parametric test for trend)

B) Tests for progressive change in the mean and median with time:

iv) Mann-Whitney U test (non-parametric test for step jump in median)

C) Tests for serial dependency of time series

v) Turning Points (Kendall non-parametric test for randomness)
vi) Rank Difference (Meachem non-parametric test for randomness)

3.5.4.1 Mann-Kendall Test

This method tests whether there is a trend in the time series data. It is a non-parametric test (Kendall, 1938). The n time series values (X_1, X_2, X_3, ….., X_n) are replaced by their relative ranks (R_1, R_2, R_3, ….., R_n) (starting at 1 for the lowest up to n).The test statistic S (Kendall's sum) is:

$$S = \sum_{i=1}^{n-1}\left[\sum_{j=i+1}^{n}\operatorname{sgn}\left(R_i - R_j\right)\right]$$

where $\operatorname{sgn}(x) = 1$ for x>0
$\operatorname{sgn}(x) = 0$ for x=0
$\operatorname{sgn}(x) = -1$ for x<0

Mann (1945) and Kendall (1975) have documented that if the null hypothesis H_o is true then for $n \geq 8$, the statistic S is approximately normally distributed with the mean and the variance as follows:

Mean: $E(S) = 0$

variance: $V(S) = \dfrac{n(n-1)(2n+5) - \sum_{i=1}^{n} t_i i(i-1)(2i+5)}{18}$

where t_i is the number of ties of extent *i*. The standardized test statistic Z is computed by:

$$Z_{MK} = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}} & S > 0 \\ 0 & S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}} & S < 0 \end{cases}$$

The standardized MK statistic Z follows the standard normal distribution with mean of zero and variance of one.

The P-value of the MK statistic (S) of sample data can be estimated using the normal CDF,

$$p = 0.5 - \Phi\left(\left|Z\right|\right) \quad (Z=Z_{MK})$$

$$\left(\Phi\left(\left|Z\right|\right) = \frac{1}{\sqrt{2\pi}}\int_0^{|Z|} e^{-t^2/2}\,dt\right)$$

If the P-value is small enough, the trend is quite unlikely to be caused by random sampling. At the significance level of 0.05, if $p \leq 0.05$, then the existing trend is considered to be statistically significant.

Critical test statistic values for various significance levels can be obtained from normal probability tables. A positive value of S indicates that there is an increasing trend and vice versa.

3.5.4.2 Spearman's Rho Test

This is a rank-based test that determines whether the correlation between two variables is significant. In trend analysis, one variable is taken as the time itself (years) and the other as the corresponding time series data. Both variables are replaced by their ranks. If the time series consists of n distinct values, the ranks will be the numbers from 1 to n, with n corresponding to the highest value in the series, n-1 to the second highest, and so on. If there are ties (equal values) in the series, each value in the tie group is assigned the same (mean) rank.

Given a sample data set{X_i, i=1,2,…,n}, the null hypothesis H_o of the Spearman's Rho test against trend tests is that all the X_i are independent and identically distributed; the alternative hypothesis is that X_i increases or decreases with I, that is, trend exists. The test statistic 'D' is given by (Sneyers, 1990)

$$D = 1 - \frac{6\sum_{i=1}^{n}\left[R(X_i) - i^2\right]}{n(n^2-1)}$$

where $R(X_i)$ is the rank of ith observation X_i in the sample of size n.

Under the null hypothesis, the distribution of 'D' is asymptotically normal with the mean and variance as follows (Lehmann, 1975; Sneyers, 1990).

$$E(D) = 0$$

$$V(D) = \frac{1}{n-1}$$

The P-value of the D of the observed sample data is estimated using the normal cumulative distribution function (CDF) as its statistics are approximately normally distributed with mean of zero and variance of V(D) for the SR statistic. Using the following standardization,

$$Z_{SR} = \frac{D}{\sqrt{V(D)}}$$

the standardized statistics Z follows the standard normal distribution Z ~ N(0,1).

The P-value of the SP statistic (D) of sample data can be estimated using the normal CDF,

$$p = 0.5 - \Phi(|Z|) \quad (Z=Z_{SR})$$

$$\left(\Phi(|Z|) = \frac{1}{\sqrt{2\pi}}\int_0^{|Z|} e^{-t^2/2}\,dt\right)$$

If the P-value is small enough, the trend is quite unlikely to be caused by random sampling. At the significance level of 0.05, if $p \leq 0.05$, then the existing trend is considered to be statistically significant.

For large samples, the quantity $r_s\sqrt{n-1}$ is approximately normally distributed with mean of 0 and variance of 1 (critical test statistic values for various significance levels therefore can be obtained from normal probability tables). This test is particularly useful for the detection of gradual change in time series.

3.5.4.3 Mean-weighted Linear Regression Test

This is a parametric test that assumes that the data come from EV1 distribution. It is previously unused and has been developed especially for the present study. The choice of EV1 distribution is based on previous studies on the Irish AM Flow Series, e.g. Flood Studies Report (1975). It tests whether there is a linear trend by examining the relationship between time (x) and the variable of interest (y). The regression gradient is estimated by:

$$b = \frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)\left(y_i - \bar{y}\right)}{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}$$

The test statistic b_s is:

$$b_s = b/\bar{y} \quad \text{where} \quad \bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$$

Under the null hypothesis of b_s=0 (i.e. the hypothesis of independent and identically distributed (EV1) series observations), the critical values for the b_s for various significance levels were calculated from the sampling distribution which was obtained by simulation. Ten thousand time series each of size n=50 are generated from the EV1 population with a mean μ=100 and coefficient of variation C_v=0.3 (a typical value for Irish AM Flow Series). Refer to **Appendix A1** for the critical values for various sample sizes and at various significance levels.

3.5.4.4 Mann-Whitney U test (Rank-Sum Test)

This test for a location difference between the two subsamples; if they are not well mixed and the entire sample is ranked, the elements of one sub sample display relatively low rank numbers while those of the other display relatively high rank numbers. The test statistic, U, reflects these differences with a low value arising when the sub samples are not well mixed. Therefore, if the observed U value is less than a certain critical value U_{cr} the hypothesis that there is no location difference between sub-samples is rejected. The quantity U_{cr} depends on the confidence level and the sub-sample sizes and is tabulated by Siegel (1956); when both sub-samples are larger than 20, U is approximately Normally distributed with mean $n_1n_2/2$ and standard deviation $[n_1n_2(n_1+n_2+1)]^{1/2}/12$.

The test statistic is calculated as the smaller of V_1 and V_2 where

$$V_1 = n_1 n_2 + \frac{n_1(n_1+1)}{2} - R_1 \text{ and}$$
$$V_2 = n_1 n_2 - V_1$$

n_1 = size of first sub-sample, n_2=size of second sub-sample, R_1=sum of ranks attributed to members of the first sub-sample in the ranked total sample.

3.5.4.5 Turning points test (Kendall's test)

This non-parametric test is based on counting "turning points" in the series, i.e. thriples of subsequent values x_{i-1},x_i,x_{i+1} such that $x_{i-1}<x_i>x_{i+1}$ or $x_{i-1}>x_i<x_{i+1}$. If N is the number of turning points, then the test statistic is

$$S = \frac{(3N - 2n + 4)\sqrt{10}}{\sqrt{16n - 29}}$$

Under the null hypothesis of independent, equally distributed values, this test statistic is normally distributed with mean 0 and variance 1(Srikanthan and MacMahon, 1983).

3.5.4.6 Rank difference test (Meacham test)

This is a nonparametric test. It involves computing differences between the ranks of subsequent values in the series. If U denotes the sum of absolute values of such rank differences then the test statistic is

$$S = \frac{(3U - n^2 + 1)\sqrt{10}}{\sqrt{(n-2)(n+1)(4n-7)}}$$

Under the null hypothesis of independent, equally distributed values, this statistic is normally distributed with mean 0 and variance 1 (Srikanthan and MacMahon, 1983).

4.0 Data

It is important to consider carefully the form and frequency of the data that should be analysed. This usually depends on the focus of the study. For floods, the biggest flow is of primary interest; for droughts, it may be the duration of low flows. Selection of which stations to use in a study is also important (Kundzewicz & Robson, 2004). For example in order to study climate change signature in river flow, data should ideally be taken from baseline rivers and should be of high quality and extend over a long period. Data should be quality-controlled before commencing any analysis of change.

In this study, Annual Maximum Flood Series for 117 stations out of 120 stations with the OPW quality grading of A1& A2 have been selected for the trend analysis. **Table 4.1** below lists the station names along with their associated record lengths and catchment areas. The stations listed in bold are stations on rivers that have experienced arterial drainage works. Out of 117 stations, 79 stations have continuous records with the lengths ranging from 17 to 58 years. The remaining 38 stations have intermittent missing records with the successive missing values in the series ranging from 1 to 16. The data series are not included with this report.

Table 4.1: Stations used for trend and randomness tests

STATION	WATERBODY	LOCATION	NATIONAL GRID REFERENCE	RECORD LENGTH (YEAR)	AREA (km^2)
6011	FANE	MOYLES MILL	H920078	48	234
6013	DEE	CHARLEVILLE	O044907	30	307
6014	GLYDE	TALLANSTOWN	N953978	30	270
6025	DEE	BURLEY	N925896	30	176
6026	LAGAN (GLYDE)	ACLINT	N893981	46	144
6031	FLURRY	CURRALHIR	J083143	18	45.3
7002	***DEEL***	***KILLYON***	***N683491***	***46***	***285***
7003	***BLACKWATER (ENFIELD)***	***CASTLERICKARD***	***N716489***	***46***	***179***
7004	***BLACKWATER (KELLS)***	***STRAMATT***	***N630833***	***48***	***256***
7005	***BOYNE***	***TRIM***	***N801569***	***47***	***1282***
7006	MOYNALTY	FYANSTOWN	N790757	19	179
7007	***BOYNE***	***BOYNE AQUEDUCT***	***N692452***	***45***	***432***
7009	BOYNE	NAVAN WEIR	N878667	29	**1610**
7010	**BLACKWATER *(KELLS)***	***LISCARTAN***	***N846689***	***46***	***717***
7011	***BLACKWATER (KELLS)***	***O'DALY'S BR.***	***N652803***	***44***	***294***
7012	***BOYNE***	***SLANE CASTLE***	***N949739***	***65***	***2408***
7033	BLACKWATER (KELLS)	VIRGINIA HATCHERY	N607875	25	129
8002	DELVIN	NAUL	O132612	21	37
8008	BROADMEADOW	BROADMEADOW	O174486	25	110
9001	RYEWATER	LEIXLIP	O005364	48	215
9002	GRIFFEEN	LUCAN	O033352	24	41.2
9010	DODDER	WALDRON'S BRIDGE	O156298	19	95.2
10021	SHANGANAGH	COMMON'S ROAD	O252230	24	30.9
11001	OWENAVORRAGH	BOLEANY	T170560	33	148
14005	BARROW	PORTARLINGTON	N540126	48	398
14006	BARROW	PASS BR	N622109	51	1096
14009	CUSHINA	CUSHINA	N552162	25	68
14013	BURREN	BALLINACARRIG	S743753	50	154
14018	BARROW	ROYAL OAK	S689614	51	2415
14019	BARROW	LEVITSTOWN	S706876	51	1660
14029	BARROW	GRAIGUENAMANAGH	S712439	47	2762

Table 4.1: Stations used for trend and randomness tests

STATION	WATERBODY	LOCATION	NATIONAL GRID REFERENCE	RECORD LENGTH (YEAR)	AREA (km^2)
14034	BARROW	U/S BESTFIELD	S717797	17	2060
15003	DININ	DININ BR.	S479628	51	298
15004	NORE	MCMAHONS BR.	S418797	51	491
16002	SUIR	BEAKSTOWN	S092552	51	512
16003	CLODIAGH	RATHKENNAN	S051530	51	246
16004	SUIR	THURLES	S128586	48	236
16005	MULTEEN	AUGHNAGROSS	R991413	30	87
16008	SUIR	NEW BRIDGE	S001341	51	1120
16009	SUIR	CAHER PARK	S052228	52	1602
18005	FUNSHION	DOWNING BR.	R823018	50	363
19001	OWENBOY	BALLEA	W709633	48	106
19020	OWENNACURRA	BALLYEDMOND	W859766	28	75
23001	GALEY	INCH BR.	Q957362	45	196
23002	***FEALE***	***LISTOWEL***	***Q997333***	***59***	***646***
23012	LEE (KERRY)	BALLYMULLEN	Q845133	18	60
24001	***MAIGUE***	***CROOM***	***R512410***	***51***	***774***
24008	MAIGUE	CASTLEROBERTS	R479438	30	805
24013	***DEEL***	***RATHKEALE***	***R360414***	***36***	***426***
24022	MAHORE	HOSPITAL	R705363	20	39.7
24082	MAIGUE	ISLANDMORE	R514399	28	764
25001	***MULKEAR***	***ANNACOTTY***	***R642576***	***49***	***646***
25002	NEWPORT	BARRINGTON'S BR.	R678549	51	223
25003	MULKEAR	ABINGTON	R715534	51	397
25005	DEAD	SUNVILLE	R777478	46	190
25006	BROSNA	FERBANE	N115243	52	1207
25014	SILVER	MILLBROOK	N135187	54	165
25017	SHANNON	BANAGHER	N004159	55	7989
25021	LITTLE BROSNA	CROGHAN	N053056	44	493
25023	LITTLE BROSNA	MILLTOWN	S069909	52	116
25025	BALLYFINBOY	BALLYHOONEY	R862959	31	160
25027	OLLATRIM	GOURDEEN	R886797	43	118
25029	NENAGH	CLARIANNA	R860822	33	301
25030	GRANEY	SCARRIFF	R641842	48	279
25044	KILMASTULLA	COOLE	R712693	40	98.9
25158	BILBOA	CAPPAMORE	R777517	18	116
26002	SUCK	ROOKWOOD	M806571	53	626
26005	SUCK	DERRYCAHILL	M825424	51	1050
26006	SUCK	WILLSBROOK	M692756	53	182
26007	SUCK	BELLAGILL	M841346	53	1184
26008	RINN	JOHNSTON'S BR.	N090864	50	292
26009	BLACK	BELLANTRA BR.	N128894	35	97
26012	***BOYLE***	***TINACARRA***	***G770018***	***48***	***520***
26017	MOUNTAIN	GILLSTOWN	M966833	49	216
26018	OWENURE	BELLAVAHAN	M951864	49	118
26019	CAMLIN	MULLAGH	N116759	51	260
26020	CAMLIN	ARGAR	N181793	33	126
26021	INNY	BALLYMAHON	N160570	30	1071
26022	FALLAN	KILMORE	N084733	33	61
26059	INNY	FINNEA BR.	N402814	23	249

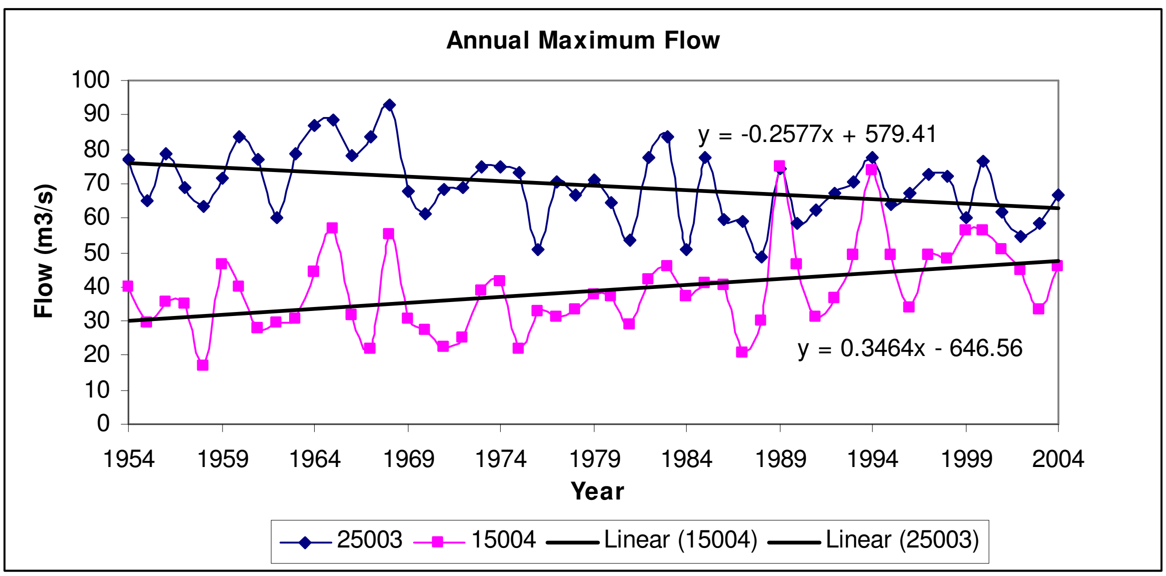
Table 4.1: Stations used for trend and randomness tests					
STATION	**WATERBODY**	**LOCATION**	**NATIONAL GRID REFERENCE**	**RECORD LENGTH (YEAR)**	**AREA (km^2)**
27001	CLAUREEN	INCH BR.	R301753	30	48
27002	FERGUS	BALLYCOREY	R344803	51	562
27003	FERGUS	CORROFIN	R286885	48	168
27070	L. INCHIQUIN	BAUNKYLE	R270892	29	---
29001	RAFORD	RATHGORGIN	M546232	40	119
29004	CLARINBRIDGE	CLARINBRIDGE	M416202	32	123
29011	DUNKELLIN	KILCOLGAN	M418185	22	373
29071	L. CUTRA	CUTRA	R482979	29	123.5
30001	***AILLE***	***CARTRONBOWER***	***M134778***	***48***	***127***
30004	***CLARE***	***CORROFIN***	***M426430***	***35***	***695***
30005	***ROBE***	***FOXHILL***	***M237681***	***49***	***250***
30007	CLARE	BALLYGADDY	M420537	31	458
31002	CASHLA	CASHLA	L978276	26	72
32012	NEWPORT	NEWPORT WEIR	L997943	24	138.3
33070	CARROWMORE L.	CARROWMORE	F838257	25	90
34001	MOY	RAHANS	G243178	36	1911
34003	MOY	FOXFORD	G267039	29	1737
34009	OWENGARVE	CURRAGHBONAUN	G453074	33	113
34011	MANULLA	GNEEVE BRIDGE	M223911	30	144
34018	CASTLEBAR	TURLOUGH	M206935	27	93
34024	POLLAGH	KILTIMAGH	M332893	29	128
35001	OWENMORE	BALLYNACARROW	G639219	29	299
35002	OWENBEG	BILLA BR.	G639257	34	90
35005	BALLYSADARE	BALLYSADARE	G669290	55	642
35071	L. MELVIN	LAREEN	G843559	30	244
35073	L. GILL	L. GILL	G715328	30	384
36010	ANNALEE	BUTLERS BR.	H408104	50	774
36011	ERNE	BELLAHILLAN	H356016	49	318
36012	ERNE	SALLAGHAN	N327931	47	263
36015	FINN	ANLORE	H537256	33	175
36018	DROMORE	ASHFIELD	H575140	50	233
36019	ERNE	BELTURBET	H359166	47	1501
36021	YELLOW	KILTYBARDAN	H091120	27	23
36027	WOODFORD	BELLAHEADY	H250156	15	324
36031	CAVAN	LISDARN	H416005	30	52
39008	LEANNAN	GARTAN BR.	C068169	33	78
39009	FERN O/L	AGHAWONEY	C179218	33	207

5.0 Exploratory Data Analysis (EDA)

5.1 As part of Exploratory Data Analysis, data for each of the selected stations have been plotted in a graph and a trend line (linear) is set to each of the Annual Maximum (AM) time series using Excel's data analysis tool. EDA shows that most of the AM Flood series are well scattered about the mean while outliers occurred in few of the series. 11 out of 117 time series showed notable upward or downward slopes when plotted against time. **Table 5.1** lists these series/station names and **Figures 5.1(a-f)** show the plots of their records against time. The Nore at MacMahon's Bridge, the Mulkear at Abington and the Nenagh at Clarianna showed significant downward trends, while the remainder (8 AM Series) showed upward trends.

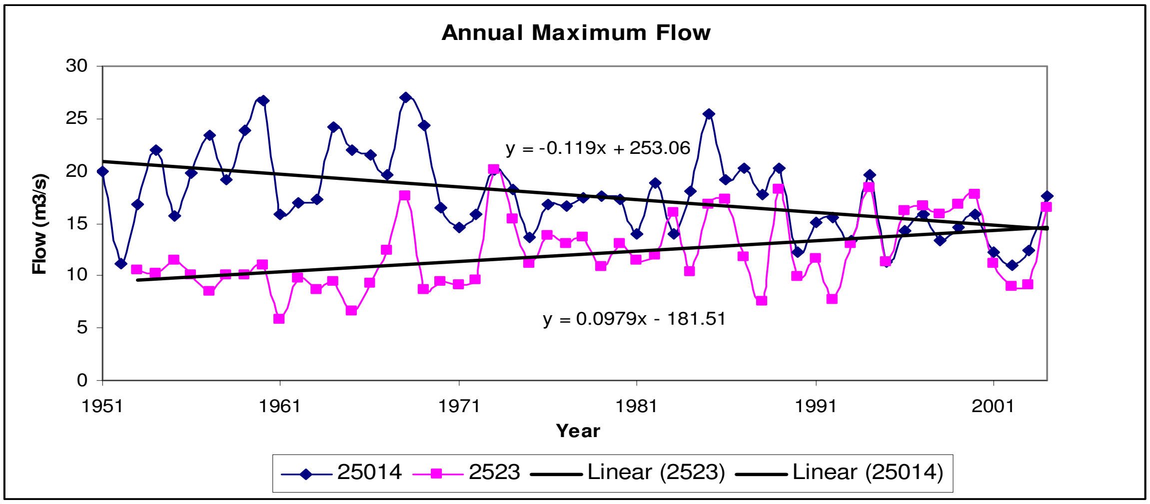
Table 5.1: Stations with significant trends

Station	Waterbody	Location
15004	NORE	MCMAHONS BR.
16003	CLODIAGH	RATHKENNAN
24001	MAIGUE	CROOM
25002	NEWPORT	BARRINGTON'S BR.
25003	MULKEAR	ABINGTON
25014	SILVER	MILLBROOK
25023	LITTLE BROSNA	MILLTOWN
25029	NENAGH	CLARIANNA
26005	SUCK	DERRYCAHILL
34018	CASTLEBAR	TURLOUGH
36011	ERNE	BELLAHILLAN

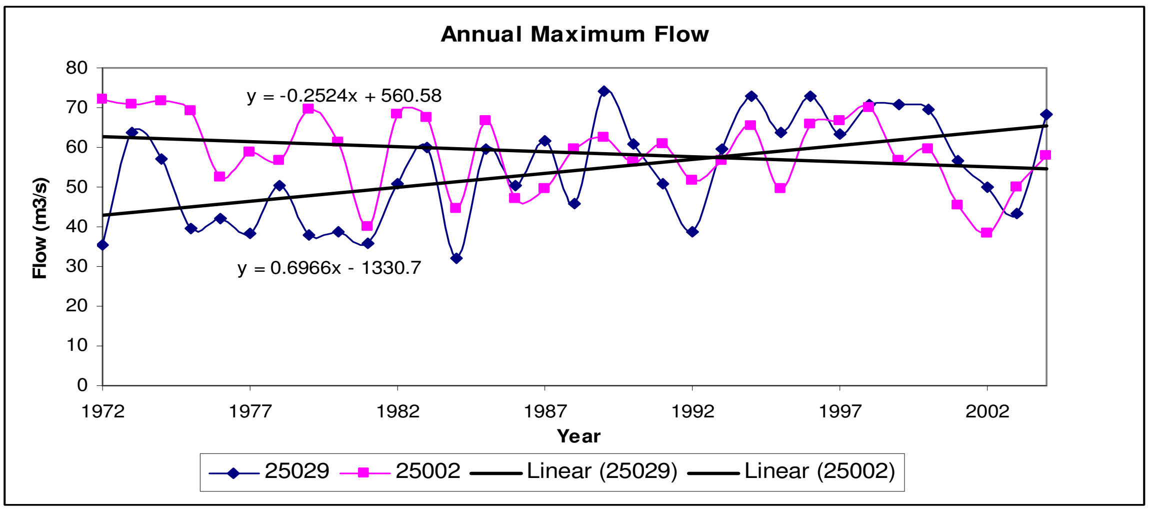


(a)

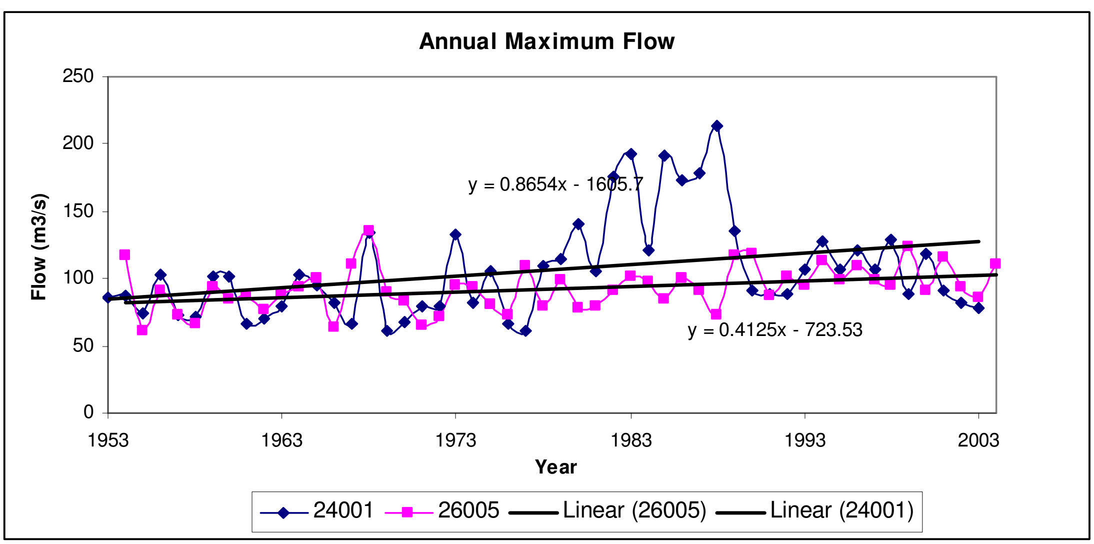
Figure 5.1(a): Plots of Annual Maximum Flows against time (EDA analysis)



(b)

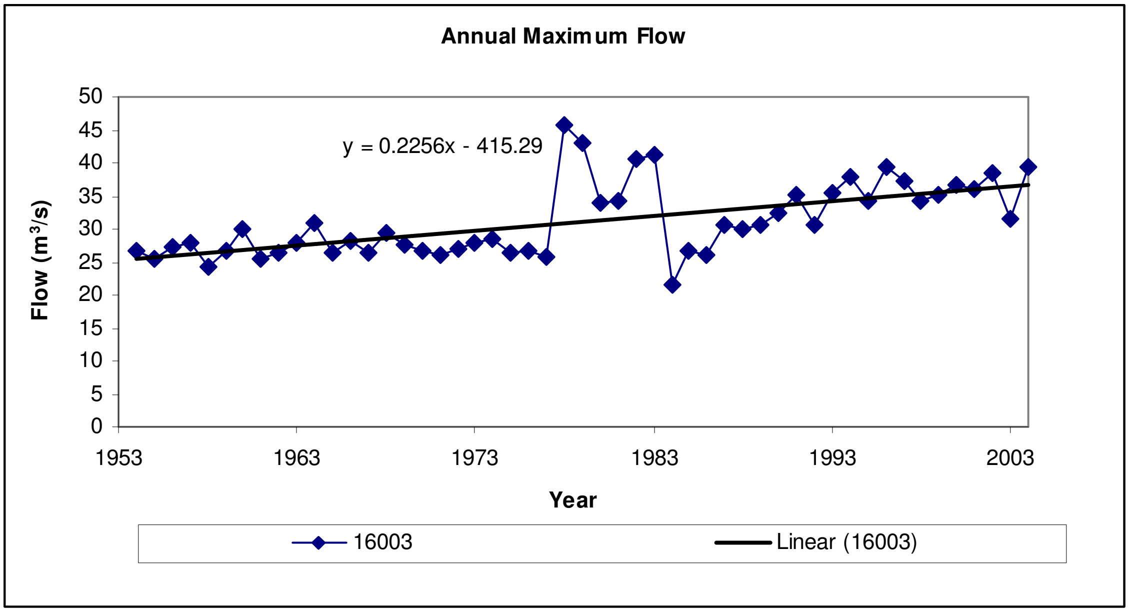


(c)

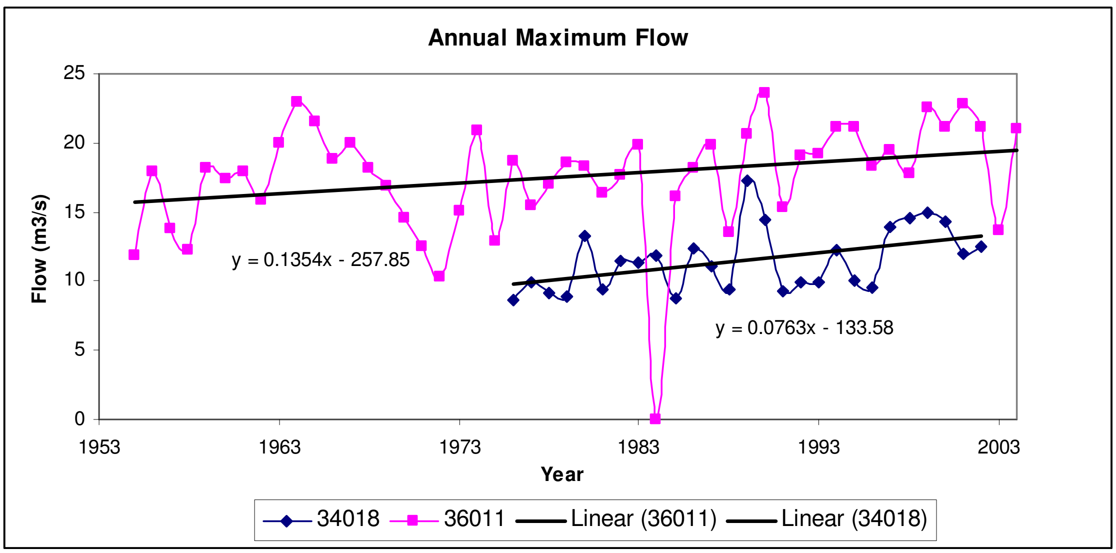


(d)

Figure 5.1(b-d): Plots of Annual Maximum Flows against time (EDA analysis)



(e)



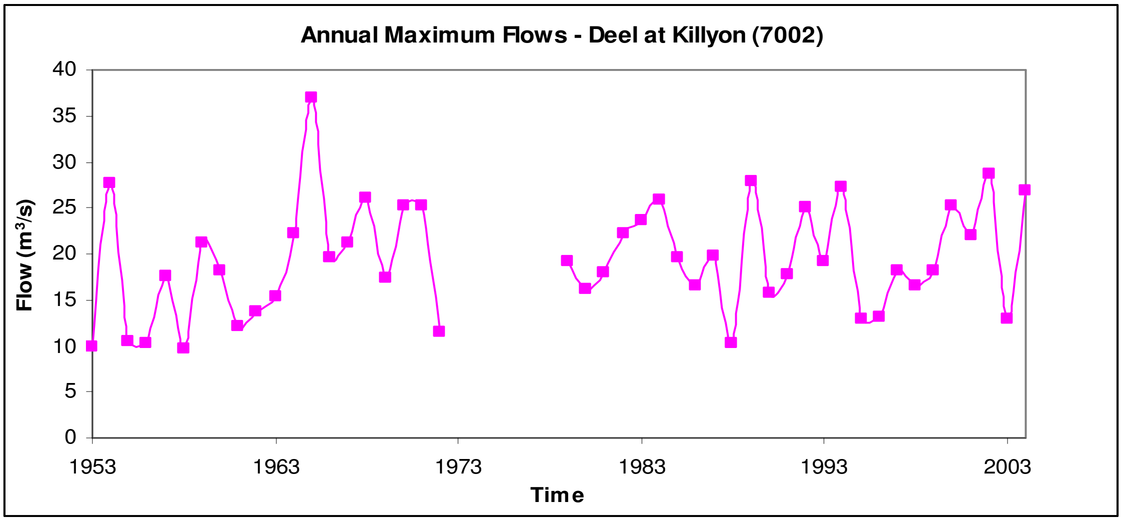
(f)

Figure 5.1(e-f): Plots of Annual Maximum Flows against time (EDA analysis)

5.2 The impact of drainage improvement works on the Annual Maximum Flows in some of the catchments is also evident from the graphical plots. These stations are listed in **Table 5.2** and their plots are shown in **Figure 5.2** overleaf. In most cases an upward step change occurred in the AM Flow series at the beginning of the post-drainage stage as shown in the plots. However, the Mulkear at Annacotty and the Aille at Cartronbower each showed a slight downward trend.

Table 5.2: Stations with arterial drainage works

Station	Waterbody	Location
7002	DEEL	KILLYON
7003	BLACKWATER (ENFIELD)	CASTLERICKARD
7004	BLACKWATER (KELLS)	STRAMATT
7005	BOYNE	TRIM
7007	BOYNE	BOYNE AQUEDUCT
7010	BLACKWATER (KELLS)	LISCARTAN
7011	BLACKWATER (KELLS)	O'DALY'S BR.
7012	BOYNE	SLANE CASTLE
23002	FEALE	LISTOWEL
24001	MAIGUE	CROOM
24013	DEEL	RATHKEALE
25001	MULKEAR	ANNACOTTY
26012	BOYLE	TINACARRA
30001	AILLE	CARTRONBOWER
30004	CLARE	CORROFIN
30005	ROBE	FOXHILL



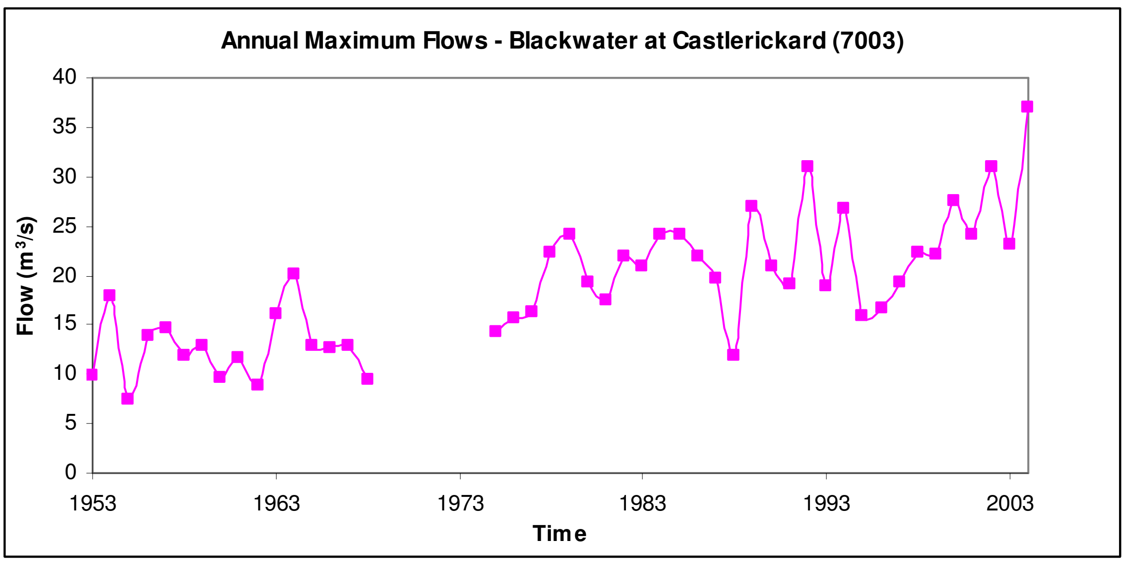
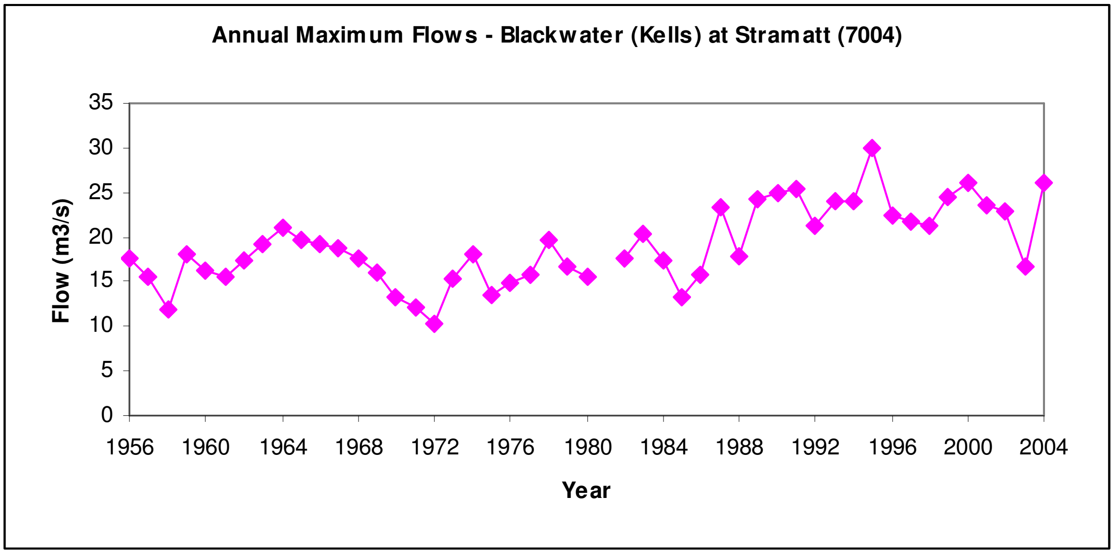
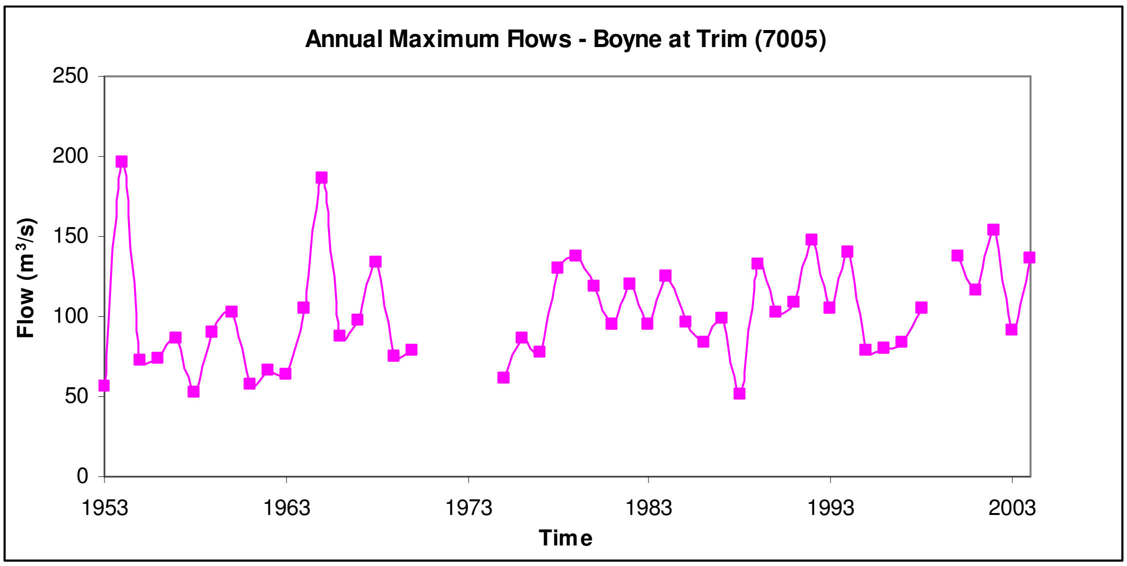


Figure 5.2:Plot of Annual Maximum Flows against time for the catchments where drainage improvement works were carried out





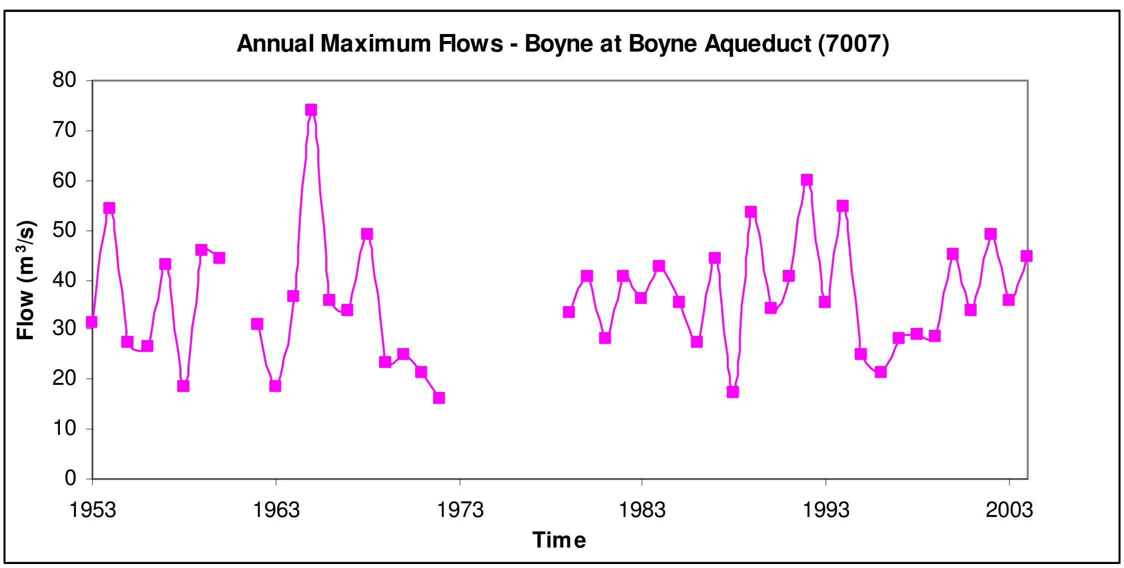
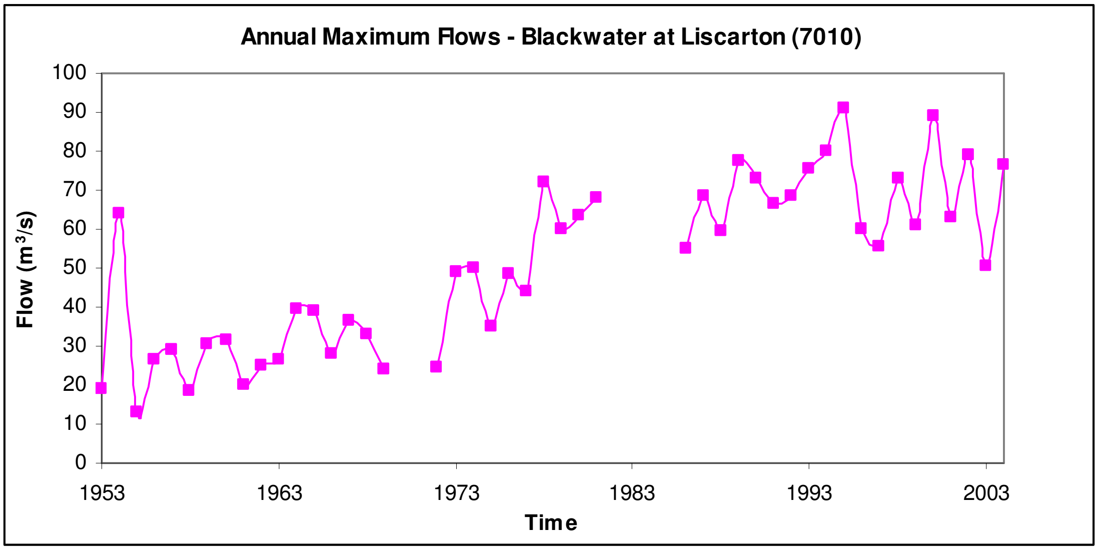
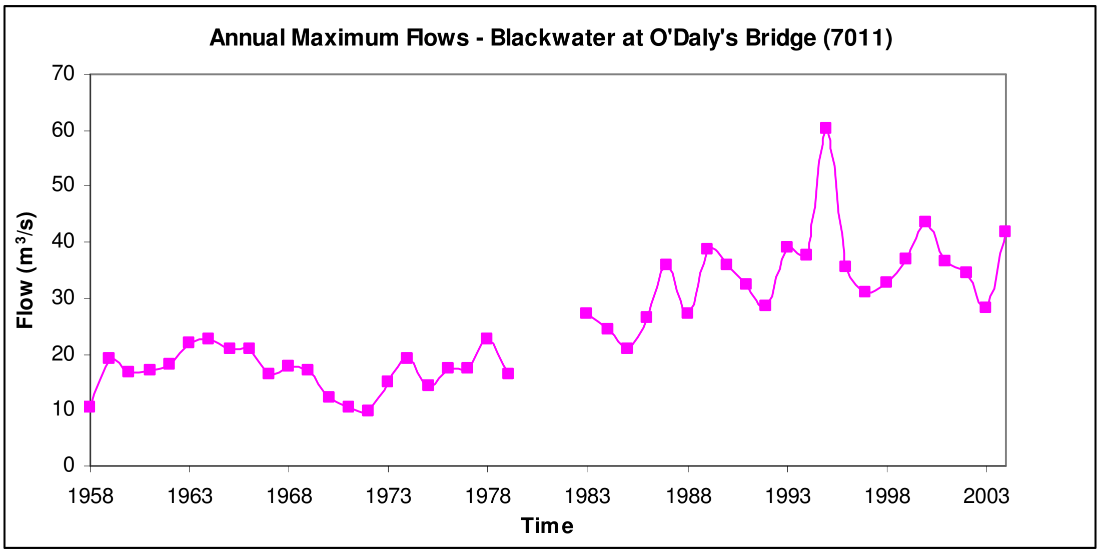


Figure 5.2:Plot of Annual Maximum Flows against time for the catchments where drainage improvement works were carried out (contd.)





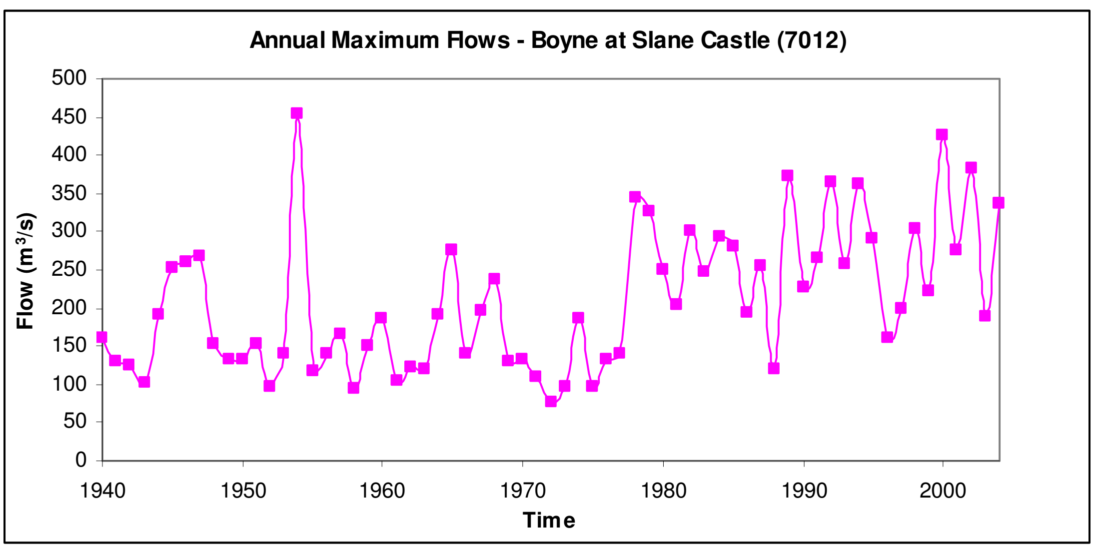
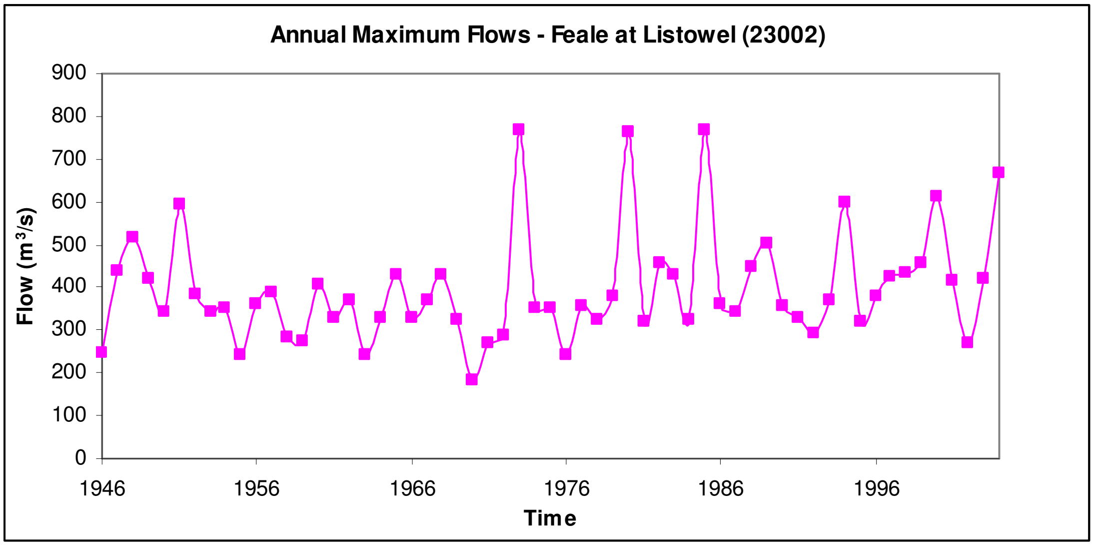
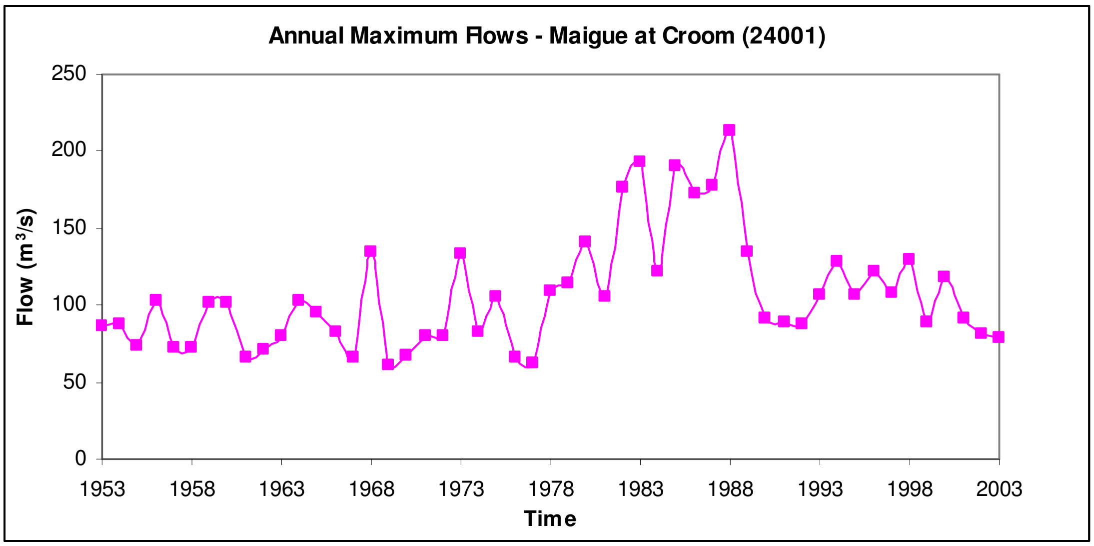


Figure 5.2:Plot of Annual Maximum Flows against time for the catchments where drainage improvement works were carried out (contd.)





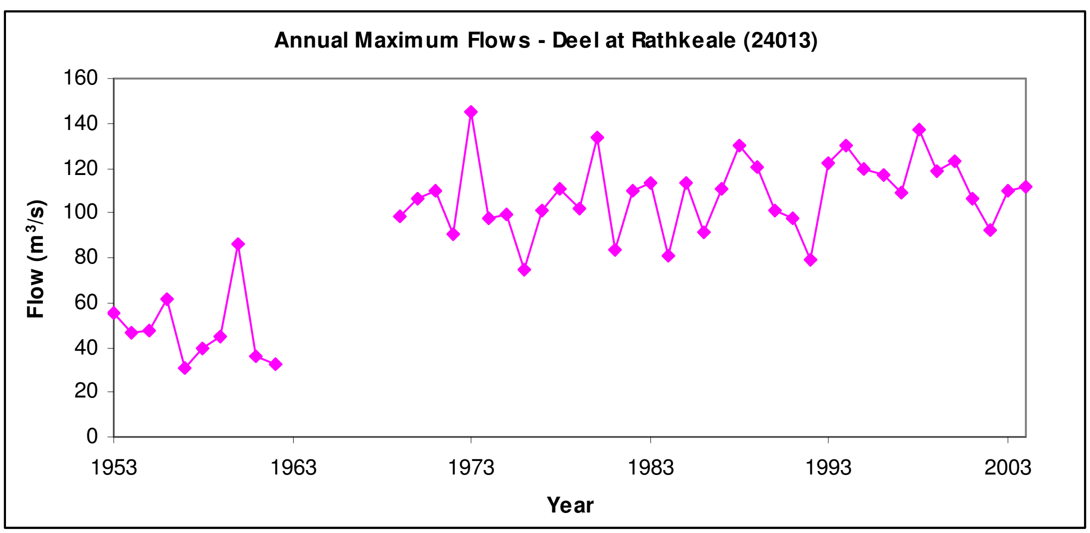
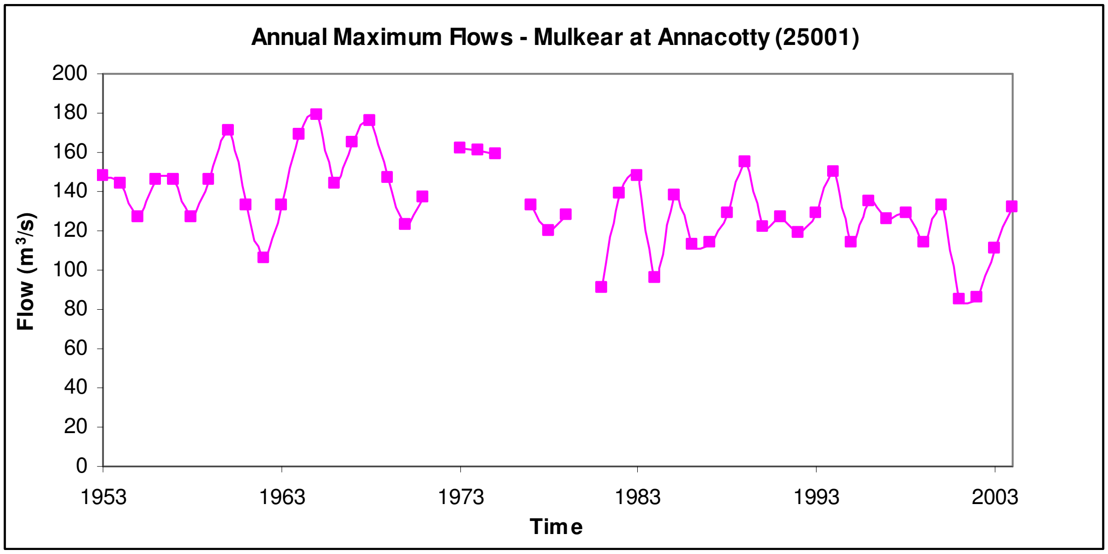
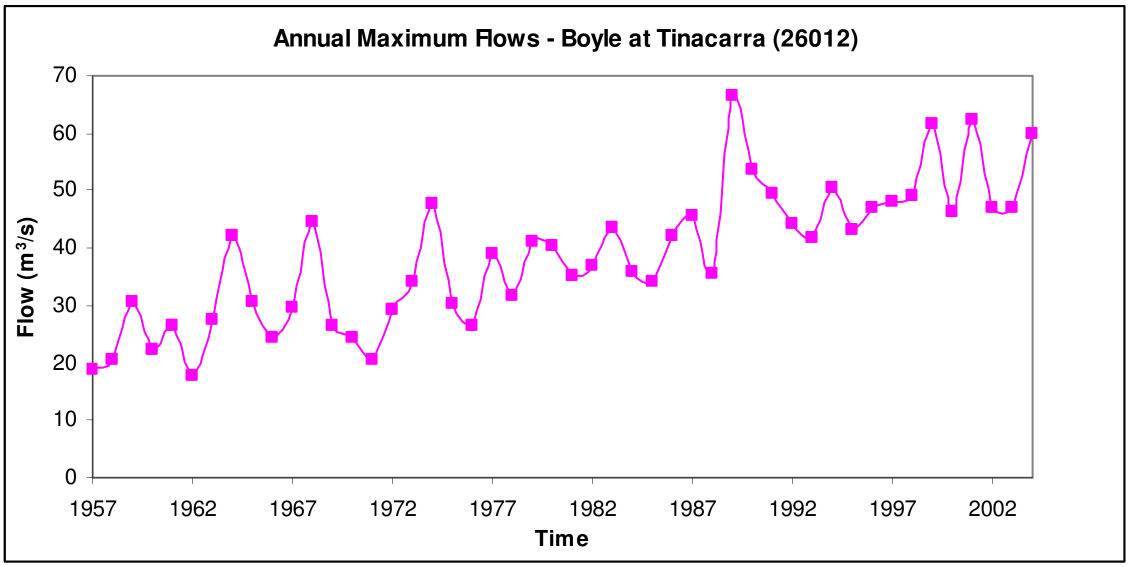


Figure 5.2: Plot of Annual Maximum Flows against time for the catchments where drainage improvement works were carried out (contd.)





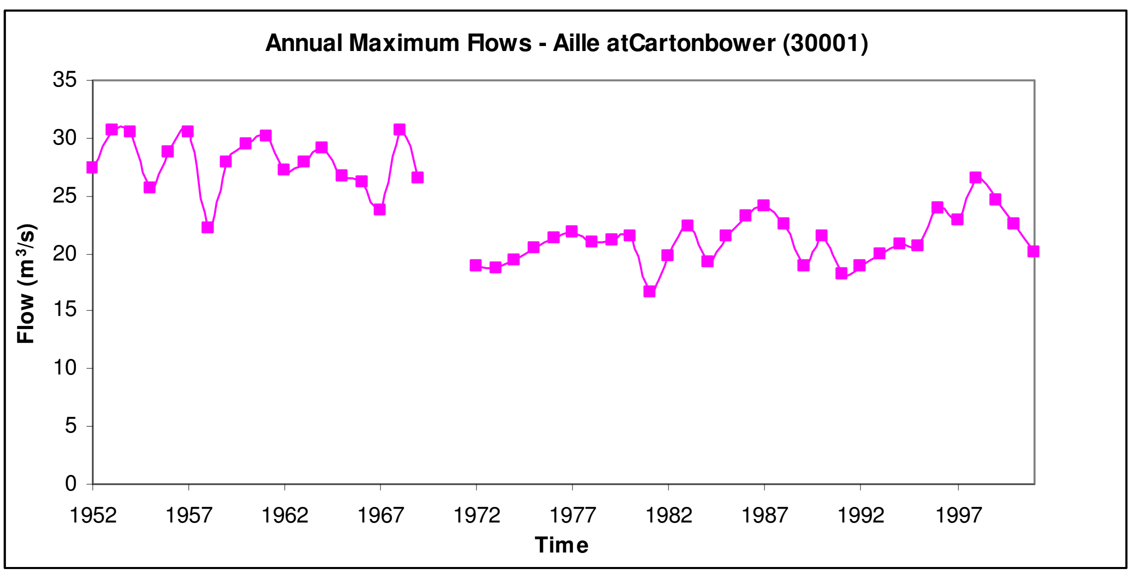
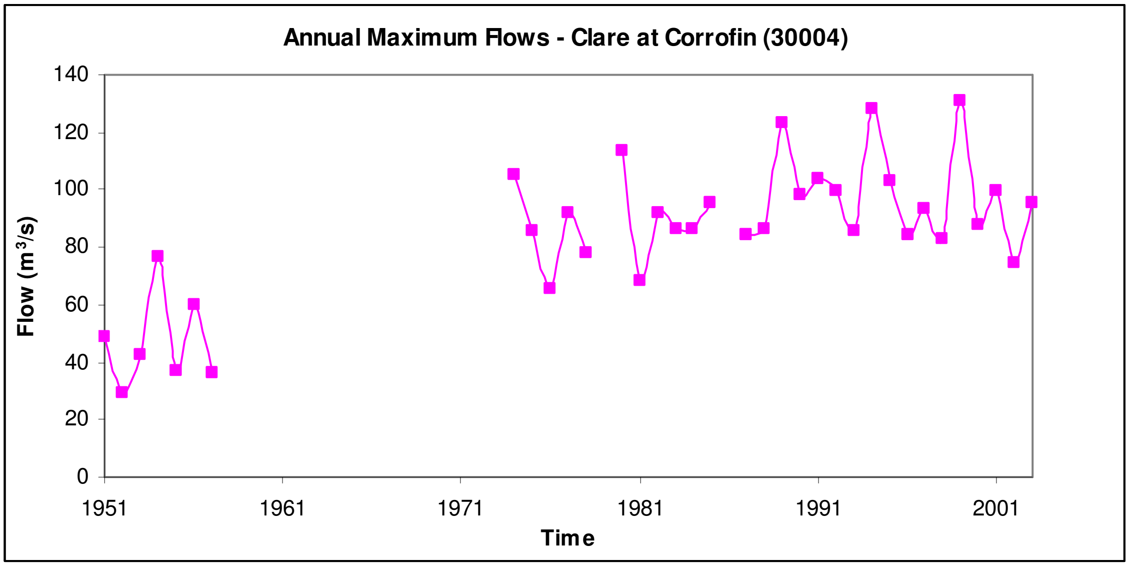


Figure 5.2:Plot of Annual Maximum Flows against time for the catchments where drainage improvement works were carried out (contd.)



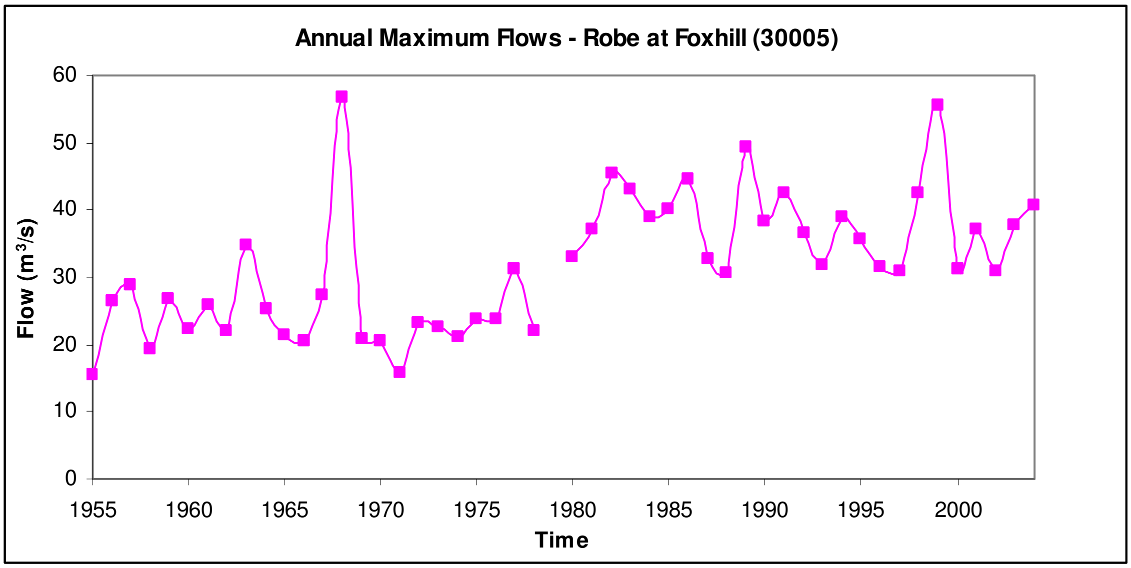


Figure 5.2:Plot of Annual Maximum Flows against time for the catchments where drainage improvement works were carried out

6.0 Trend Analysis and Results

6.1 Statistical trend tests of the Annual Maximum Flow series were applied on the following two data scenarios:

1. Full Annual Maximum Flow Series (**AM Series - 91 stations**)
2. Median Series of non-overlapping five year periods derived from the Annual Maximum Flow Series (**Median Series – 117 stations**)

Selection of 91 stations in the scenario 1 data set was based on the availability of continuous flow records and on the evidence of drainage improvement works carried out on the river channels. All stations where drainage improvement works were carried out have been excluded from the scenario 1 data set but were included in the Median Series data set (scenario 2). In the data scenario 1, 15 stations have a small number of intermittent missing values. Five yearly median series derived from the AM flow records of all 117 station were used in trend analysis under the data scenario 2. The median series are considered in order to compensate for any undesirable data properties such as presence of outliers, high autocorrelations. Refer to **Appendix A2** for the plots of standardised median series (each of the five yearly median values divided by the median of the full time series) versus time for all stations.

6.2 Trends in both data scenarios have been analysed using the tests described in Section 3.5. A Fortran program was developed and used in carrying out all relevant calculations.

6.3 The test statistic values for each test on each of the stations are presented in **Table 6.1** and **Table 6.2** for the data scenarios of 1 & 2 respectively. The significance of all computed test statistics have been judged at two levels of significance: 1% and 5%. Where at least one test statistics was found to be significant at the significance level of 1% that station's row is highlighted in green and the associated significant levels are mentioned therein. Critical values associated with all test statistics have been extracted from published statistical tables**.** Results of each test on all records for both data scenarios are summarised in **Table 6.3.**

Table 6.1: Trend test Results (Full Annual Maximum Flow Series)

STATION	Record Length (years)	Mann-Kendall		Spearman's Rho		Linear Regression		Mann Whitney U Test		Turning Point Test		Rank Diff. Test	
		P-value	Result	P-value	Result	P-value	Result	P-value	Result	P-value	Result	P-value	Result
6011	48	0.248	NS	0.281	NS	0.558	NS	0.117	NS	0.415	NS	0.327	NS
6013	30	0.803	NS	0.963	NS	0.944	NS	0.254	NS	0.551	NS	0.770	NS
6014	30	0.301	NS	0.365	NS	0.234	NS	0.852	NS	0.234	NS	0.267	NS
6025	30	0.027	S(5%)	0.035	S(5%)	0.253	NS	0.008	S(1%)	0.551	NS	0.968	NS
6026	46	0.130	NS	0.125	NS	0.038	S(5%)	0.860	NS	0.812	NS	0.319	NS
7006	19	0.972	NS	0.913	NS	0.983	NS	0.221	NS	0.127	NS	0.853	NS
7009	29	0.409	NS	0.336	NS	0.236	NS	0.012	S(5%)	0.172	NS	0.453	NS
7033	25	0.176	NS	0.184	NS	0.133	NS	0.064	S(10%)	0.870	NS	0.171	NS
8002	21	0.740	NS	0.814	NS	0.637	NS	0.097	S(10%)	0.367	NS	0.819	NS
9001	48	0.644	NS	0.601	NS	0.699	NS	0.877	NS	0.642	NS	0.498	NS
9002	24	0.286	NS	0.363	NS	0.001	S(1%)	0.707	NS	0.401	NS	0.502	NS
10021	24	0.172	NS	0.105	NS	0.186	NS	0.006	S(1%)	0.737	NS	0.587	NS
11001	33	0.745	NS	0.728	NS	0.631	NS	0.759	NS	0.571	NS	0.910	NS

Table 6.1: Trend test Results (Full Annual Maximum Flow Series)

STATION	Record Length (years)	Mann-Kendall		Spearman's Rho		Linear Regression		Mann Whitney U Test		Turning Point Test		Rank Diff. Test	
		P-value	Result	P-value	Result	P-value	Result	P-value	Result	P-value	Result	P-value	Result
14006	51	0.153	NS	0.144	NS	0.144	NS	0.777	NS	0.143	NS	0.643	NS
14009	25	0.072	S(10%)	0.064	S(10%)	0.214	NS	0.663	NS	0.412	NS	0.560	NS
14013	50	0.300	NS	0.255	NS	0.300	NS	0.509	NS	0.733	NS	0.934	NS
14018	51	0.065	S(10%)	0.062	S(10%)	0.111	NS	0.019	S(5%)	0.910	NS	0.777	NS
14019	51	0.929	NS	0.852	NS	0.984	NS	0.492	NS	0.215	NS	0.595	NS
14034	17	0.564	NS	0.700	NS	0.748	NS	0.229	NS	1.000	NS	0.416	NS
15003	51	0.968	NS	0.977	NS	0.763	NS	0.095	S(10%)	0.910	NS	0.477	NS
15004	51	0.002	S(1%)	0.002	S(1%)	0.001	S(1%)	0.000	S(1%)	0.024	S(5%)	0.024	S(5%)
16002	51	0.121	NS	0.131	NS	0.091	S(10%)	0.865	NS	0.215	NS	0.874	NS
16003	51	0.000	S(1%)	0.000	S(1%)	0.008	S(1%)	0.000	S(1%)	0.910	NS	0.000	S(1%)
16004	48	0.319	NS	0.348	NS	0.429	NS	0.734	NS	0.816	NS	0.310	NS
16005	30	0.972	NS	0.930	NS	0.724	NS	0.309	NS	0.882	NS	0.374	NS
16008	51	0.024	S(5%)	0.018	S(5%)	0.317	NS	0.002	S(1%)	0.215	NS	0.440	NS
16009	52	0.068	S(10%)	0.076	S(10%)	0.321	NS	0.015	S(5%)	0.655	NS	0.959	NS
18005	50	0.118	NS	0.129	NS	0.151	NS	0.014	S(5%)	0.733	NS	0.352	NS
19001	48	0.756	NS	0.581	NS	0.754	NS	0.503	NS	0.561	NS	0.461	NS
19020	28	0.086	S(10%)	0.069	S(10%)	0.030	S(5%)	0.223	NS	0.757	NS	0.787	NS
23001	45	0.256	NS	0.338	NS	0.310	NS	0.021	S(5%)	0.548	NS	0.669	NS
23012	18	0.058	S(10%)	0.046	S(5%)	0.147	NS	0.001	S(1%)	0.001	S(1%)	0.002	S(1%)
24001	51	0.008	S(1%)	0.003	S(1%)	0.003	S(1%)	0.000	S(1%)	0.573	NS	0.000	S(1%)
24008	30	0.432	NS	0.424	NS	0.356	NS	0.309	NS	0.882	NS	0.582	NS
24022	20	0.015	S(5%)	0.015	S(5%)	0.001	S(1%)	0.000	S(1%)	1.000	NS	0.110	NS
24082	28	0.040	S(5%)	0.029	S(5%)	0.042	S(5%)	0.085	S(10%)	0.757	NS	0.162	NS
25002	51	0.004	S(1%)	0.004	S(1%)	0.123	NS	0.025	S(5%)	0.573	NS	0.031	S(5%)
25003	51	0.008	S(1%)	0.005	S(1%)	0.176	NS	0.076	S(10%)	0.024	S(5%)	0.149	NS
25006	52	0.336	NS	0.227	NS	0.149	NS	0.552	NS	0.655	NS	0.142	NS
25014	54	0.001	S(1%)	0.001	S(1%)	0.007	S(1%)	0.017	S(5%)	0.584	NS	0.009	S(1%)
25017	55	0.133	NS	0.163	NS	0.329	NS	0.031	S(5%)	0.665	NS	0.738	NS
25021	44	0.015	S(5%)	0.032	S(5%)	0.354	NS	0.001	S(1%)	0.144	NS	0.220	NS
25023	52	0.005	S(1%)	0.004	S(1%)	0.002	S(1%)	0.001	S(1%)	0.577	NS	0.026	S(5%)
25027	43	0.121	NS	0.116	NS	0.219	NS	0.002	S(1%)	0.805	NS	0.808	NS
25029	33	0.007	S(1%)	0.004	S(1%)	0.014	S(5%)	0.000	S(1%)	0.571	NS	0.058	S(10%)
25030	48	0.290	NS	0.282	NS	0.655	NS	0.228	NS	0.561	NS	0.996	NS
25158	18	0.096	S(10%)	0.209	NS	0.342	NS	0.047	S(5%)	0.116	NS	0.559	NS
26002	53	0.759	NS	0.810	NS	0.579	NS	0.346	NS	0.185	NS	0.925	NS
26005	51	0.003	S(1%)	0.004	S(1%)	0.105	NS	0.001	S(1%)	0.910	NS	0.681	NS
26006	53	0.203	NS	0.277	NS	0.279	NS	0.057	S(10%)	0.008	S(1%)	0.272	NS
26007	53	0.730	NS	0.739	NS	0.990	NS	0.233	NS	1.000	NS	0.167	NS
26008	50	0.044	S(5%)	0.052	S(10%)	0.391	NS	0.012	S(5%)	0.088	S(10%)	0.071	S(10%)
26009	35	0.191	NS	0.229	NS	0.612	NS	0.987	NS	0.681	NS	0.496	NS
26017	49	0.241	NS	0.417	NS	0.817	NS	0.059	S(10%)	0.066	S(10%)	0.167	NS
26018	49	0.163	NS	0.198	NS	0.440	NS	0.052	S(10%)	0.420	NS	0.116	NS
26019	51	0.038	S(5%)	0.051	S(10%)	0.180	NS	0.246	NS	0.367	NS	0.550	NS
26020	33	0.133	NS	0.221	NS	0.307	NS	0.000	S(1%)	0.777	NS	0.276	NS
26021	30	0.830	NS	0.960	NS	0.676	NS	0.361	NS	0.766	NS	0.419	NS
26022	33	0.448	NS	0.489	NS	0.588	NS	0.589	NS	0.571	NS	0.589	NS
26059	23	0.023	S(5%)	0.028	S(5%)	0.227	NS	0.829	NS	0.303	NS	0.359	NS
27001	30	0.015	S(5%)	0.016	S(5%)	0.280	NS	0.068	S(10%)	0.766	NS	0.402	NS
27002	51	0.266	NS	0.292	NS	0.418	NS	0.078	S(10%)	0.215	NS	0.770	NS
27003	48	0.488	NS	0.464	NS	0.713	NS	0.773	NS	0.201	NS	0.864	NS

Table 6.1: Trend test Results (Full Annual Maximum Flow Series)													
STATION	Record Length (years)	Mann-Kendall		Spearman's Rho		Linear Regression		Mann Whitney U Test		Turning Point Test		Rank Diff. Test	
		P-value	Result	P-value	Result	P-value	Result	P-value	Result	P-value	Result	P-value	Result
27070	29	0.378	NS	0.371	NS	0.033	S(5%)	0.879	NS	0.006	S(1%)	0.001	S(1%)
29004	32	0.517	NS	0.366	NS	0.590	NS	0.070	S(10%)	0.031	S(5%)	0.902	NS
29011	22	0.085	S(10%)	0.065	S(10%)	0.030	S(5%)	0.045	S(5%)	0.159	NS	0.606	NS
29071	29	0.051	S(10%)	0.047	S(5%)	0.113	NS	0.000	S(1%)	1.000	NS	0.473	NS
30007	31	0.586	NS	0.453	NS	0.968	NS	0.594	NS	0.770	NS	0.314	NS
31002	26	0.567	NS	0.476	NS	0.529	NS	0.228	NS	0.054	S(10%)	0.075	S(10%)
32012	24	0.655	NS	0.755	NS	0.923	NS	0.977	NS	0.737	NS	0.977	NS
33070	25	0.118	NS	0.128	NS	0.450	NS	0.007	S(1%)	0.511	NS	0.091	S(10%)
34001	36	0.017	S(5%)	0.014	S(5%)	0.164	NS	0.004	S(1%)	0.787	NS	0.166	NS
34003	29	0.764	NS	0.775	NS	0.738	NS	0.034	S(5%)	0.363	NS	0.565	NS
34009	33	0.938	NS	0.726	NS	0.919	NS	0.368	NS	0.024	S(5%)	0.077	S(10%)
34011	30	0.284	NS	0.224	NS	0.433	NS	0.245	NS	0.882	NS	0.003	S(1%)
34018	27	0.007	S(1%)	0.006	S(1%)	0.097	S(10%)	0.001	S(1%)	0.753	NS	0.128	NS
34024	29	0.722	NS	0.730	NS	0.691	NS	0.285	NS	0.363	NS	0.632	NS
35001	29	0.311	NS	0.281	NS	0.373	NS	0.432	NS	0.006	S(1%)	0.038	S(5%)
35002	34	0.328	NS	0.385	NS	0.470	NS	0.196	NS	0.329	NS	0.369	NS
35071	30	0.261	NS	0.209	NS	0.277	NS	0.018	S(5%)	0.457	NS	0.361	NS
35073	30	0.695	NS	0.770	NS	0.917	NS	0.263	NS	0.297	NS	0.968	NS
36010	50	0.122	NS	0.175	NS	0.330	NS	0.029	S(5%)	0.494	NS	0.013	S(5%)
36011	49	0.004	S(1%)	0.005	S(1%)	0.097	S(10%)	0.001	S(1%)	0.420	NS	0.038	S(5%)
36012	47	0.011	S(5%)	0.009	S(1%)	0.029	S(5%)	0.009	S(1%)	0.078	S(10%)	0.003	S(1%)
36015	33	0.020	S(5%)	0.015	S(5%)	0.066	S(10%)	0.001	S(1%)	0.479	NS	0.101	NS
36018	50	0.019	S(5%)	0.020	S(5%)	0.132	NS	0.014	S(5%)	1.000	NS	0.798	NS
36019	47	0.011	S(5%)	0.017	S(5%)	0.138	NS	0.001	S(1%)	0.158	NS	0.010	S(1%)
36021	27	0.662	NS	0.596	NS	0.521	NS	0.789	NS	0.270	NS	0.287	NS
36031	30	0.169	NS	0.213	NS	0.567	NS	0.534	NS	0.766	NS	0.793	NS
39008	33	0.780	NS	0.763	NS	0.758	NS	0.113	NS	0.571	NS	0.651	NS
39009	33	0.828	NS	0.825	NS	0.943	NS	0.126	NS	0.777	NS	0.972	NS

**S/5% denotes that test statistic is significant at the 5% significance level*

Table 6.2: Trend test results (Median Series)													
STATION	Record Length (years)	Mann-Kendall		Spearman's Rho		Linear Regression		Mann Whitney U Test		Turning Point Test		Rank Diff. Test	
		Test Statistic (S)	Result	Test Statistic (D)	Result	Test Statistic (b_s)	Result	Test Statistic (U)	Result	Test Statistic (N)	Result	Test Statistic (U)	Result
6011	10	12	NS	0.32	NS	0.01	NS	39	S(5%)	4	NS	29.5	NS
6013	6	1	NS	0.20	NS	0.02	NS	14	NS	3	NS	14	NS
6014	6	0	NS	0.04	NS	-0.03	NS	12.5	NS	4	NS	16.5	S(5%)
6025	6	12	S(5%)	0.90	S(5%)	0.04	NS	18	S(1%)	2	NS	8	NS
6026	10	-11	NS	-0.39	NS	-0.03	NS	29	NS	6	NS	32	NS
6031	5	0	NS	0.10	NS	-0.03	NS	14	S(1%)	3	NS	9	NS
7002	11	17	NS	0.47	NS	0.03	NS	51	S(1%)	5	NS	35	NS
7003	10	25	S(5%)	0.78	S(1%)	0.08	NS	45	S(1%)	3	S(10%)	18	S(1%)
7004	10	25	S(5%)	0.70	S(5%)	0.05	S(1%)	40	S(1%)	4	NS	22	S(10%)
7005	11	15	NS	0.35	NS	0.02	S(10%)	46	S(1%)	7	NS	41	NS
7006	4	0	NS	0.00	NS	0.01	NS	8	S(5%)	2	NS	7	S(5%)
7007	11	11	NS	0.24	NS	0.01	NS	42	S(5%)	7	NS	45	NS
7009	6	-3	NS	-0.09	NS	0.02	NS	12	NS	3	NS	11	NS

Table 6.2: Trend test results (Median Series)

STATION	Record Length (years)	Mann-Kendall		Spearman's Rho		Linear Regression		Mann Whitney U Test		Turning Point Test		Rank Diff. Test	
		Test Statistic (S)	Result	Test Statistic (D)	Result	Test Statistic (b_s)	Result	Test Statistic (U)	Result	Test Statistic (N)	Result	Test Statistic (U)	Result
7010	11	38	S(1%)	0.87	S(1%)	0.09	NS	56	S(1%)	6	NS	22	S(1%)
7011	10	31	S(1%)	0.84	S(1%)	0.12	S(1%)	43	S(1%)	4	NS	18	S(1%)
7012	13	37	S(5%)	0.62	S(5%)	0.06	S(1%)	67	S(1%)	6	NS	46	NS
7033	5	4	NS	0.50	NS	0.06	S(1%)	14	S(1%)	2	NS	9	NS
8002	6	1	NS	0.14	NS	0.04	NS	13	NS	3	NS	13	NS
8008	6	-5	NS	-0.37	NS	-0.18	NS	12	NS	3	NS	14	NS
9001	10	-7	NS	-0.15	NS	0.00	S(1%)	29	NS	5	NS	36	NS
9002	6	7	NS	0.60	NS	0.12	NS	17	S(1%)	3	NS	13	NS
9010	4	0	NS	0.20	NS	0.09	S(5%)	7	NS	1	NS	5	NS
10021	5	4	NS	0.60	NS	0.11	NS	13	S(1%)	2	NS	7	NS
11001	7	5	NS	0.29	NS	0.02	NS	22	S(1%)	2	NS	15	NS
14005	10	-28	S(5%)	-0.80	S(1%)	-0.05	NS	22.5	NS	5	NS	23	S(10%)
14006	11	-14	NS	-0.37	NS	-0.03	S(10%)	35	NS	7	NS	42.5	NS
14009	5	-8	S(10%)	-0.90	S(5%)	-0.07	S(10%)	10	S(5%)	2	NS	6	NS
14013	10	-3	NS	-0.13	NS	0.00	NS	28	NS	4	NS	31	NS
14018	11	17	NS	0.27	NS	0.01	NS	43	S(5%)	6	NS	36.5	NS
14019	11	0	NS	-0.03	NS	-0.01	NS	38	NS	5	NS	38	NS
14029	12	-10	NS	-0.21	NS	-0.01	NS	40	NS	8	NS	54	NS
14034	4	-2	NS	-0.40	NS	-0.04	NS	6	NS	1	NS	5	NS
15003	11	-11	NS	-0.21	NS	0.00	NS	38	NS	6	NS	48	NS
15004	11	27	S(5%)	0.66	S(5%)	0.04	NS	49	S(1%)	4	NS	20	S(1%)
16002	11	-25	S(10%)	-0.56	S(5%)	-0.02	S(10%)	32	NS	6	NS	39.5	NS
16003	11	35	S(1%)	0.81	S(1%)	0.04	NS	50	S(1%)	4	NS	20.5	S(1%)
16004	11	-20	NS	-0.44	NS	-0.01	NS	34.5	NS	6	NS	42	NS
16005	6	2	NS	0.04	NS	0.00	NS	16	S(5%)	3	NS	11	NS
16008	11	17	NS	0.39	NS	0.01	NS	42	S(5%)	8	NS	41	NS
16009	11	10	NS	0.32	NS	0.01	NS	45	S(1%)	8	NS	45	NS
18005	10	19	NS	0.56	S(5%)	0.02	NS	41	S(1%)	6	NS	30	NS
19001	10	1	NS	0.10	NS	0.00	NS	38	S(5%)	4	NS	29	NS
19020	6	-11	S(10%	) -0.886	S(5%)	-0.10	NS	10	NS	2	NS	7	S(5%)
23001	9	-2	NS	0.00	NS	0.01	S(10%)	28	S(10%)	3	NS	24	NS
23002	12	18	NS	0.36	NS	0.02	NS	52	S(5%)	6	NS	41	NS
23012	5	0	NS	0.00	NS	0.02	NS	11	S(1%)	2	NS	10	NS
24001	11	23	S(10%	) 0.573	S(5%)	0.04	NS	53	S(1%)	6	NS	27	S(10%)
24008	6	3	NS	0.31	NS	0.01	S(10%)	16	S(5%)	3	NS	14	NS
24013	11	34	S(1%)	0.81	S(1%)	0.08	NS	56	S(1%)	6	NS	27	S(10%)
24022	4	4	NS	0.80	NS	0.14	S(1%)	8	S(5%)	1	NS	4	NS
24082	6	8	NS	0.64	NS	0.08	NS	18	S(1%)	2	NS	9.5	NS
25001	11	-36	S(1%)	-0.80	S(1%)	-0.03	NS	31	NS	4	NS	21.5	S(1%)
25002	11	-24	S(10%	) -0.602	S(5%)	-0.02	NS	32.5	NS	7	NS	33	NS
25003	11	-29	S(5%)	-0.75	S(1%)	-0.02	NS	30	NS	6	NS	27	S(10%)
25005	11	11	NS	0.28	NS	0.01	NS	43	S(5%)	6	NS	41	NS
25006	11	-13	NS	-0.38	NS	-0.03	NS	31	NS	7	NS	40	NS
25014	11	-27	S(5%)	-0.65	S(5%)	-0.03	NS	32	NS	5	NS	31	NS
25017	11	25	S(10%	) 0.564	S(5%)	0.02	NS	45	S(1%)	6	NS	32	NS
25021	9	24	S(5%)	0.83	S(1%)	0.03	NS	37	S(1%)	3	NS	13	S(1%)
25023	11	19	NS	0.63	S(5%)	0.04	NS	54	S(1%)	6	NS	27	S(10%)
25025	7	10	NS	0.60	NS	0.03	S(10%)	21.5	S(1%)	2	NS	11	NS
25027	9	6	NS	0.17	NS	0.00	NS	29	S(5%)	4	NS	20	NS
25029	7	6	NS	0.42	NS	0.05	NS	22	S(1%)	2	NS	13	NS

Table 6.2: Trend test results (Median Series)

STATION	Record Length (years)	Mann-Kendall		Spearman's Rho		Linear Regression		Mann Whitney U Test		Turning Point Test		Rank Diff. Test	
		Test Statistic (S)	Result	Test Statistic (D)	Result	Test Statistic (b_s)	Result	Test Statistic (U)	Result	Test Statistic (N)	Result	Test Statistic (U)	Result
25030	10	5	NS	0.15	NS	0.01	NS	35	NS	7	NS	32	NS
25044	9	2	NS	0.13	NS	0.01	NS	30	S(5%)	5	NS	33	NS
25158	4	2	NS	0.40	NS	0.06	NS	7	NS	1	NS	5	NS
26002	11	0	NS	0.02	NS	0.00	NS	41	S(10%)	3	S(5%)	29	S(10%)
26005	11	10	NS	0.20	NS	0.00	NS	41	S(10%)	4	NS	36	NS
26006	11	7	NS	0.10	NS	-0.01	NS	39	NS	7	NS	44	NS
26007	11	-8	NS	-0.21	NS	-0.01	NS	36.5	NS	5	NS	34	NS
26008	10	12	NS	0.28	NS	0.02	NS	34	NS	5	NS	29	NS
26009	7	-9	NS	-0.54	NS	-0.03	NS	15	NS	3	NS	14	NS
26012	10	37	S(1%)	0.94	S(1%)	0.09	NS	45	S(1%)	3	S(10%)	13	S(1%)
26017	10	10	NS	0.14	NS	0.01	S(1%)	31.5	NS	3	S(10%)	23	S(10%)
26018	10	10	NS	0.18	NS	0.01	NS	31	NS	2	S(1%)	22	S(10%)
26019	11	-19	NS	-0.50	S(10%)	-0.03	NS	31.5	NS	4	NS	35	NS
26020	7	-3	NS	-0.25	NS	-0.01	NS	20	S(1%)	2	NS	15	NS
26021	6	-2	NS	-0.10	NS	-0.01	NS	11.5	NS	3	NS	13	NS
26022	7	-11	NS	-0.68	S(10%)	-0.05	NS	19	S(5%)	2	NS	10	S(5%)
26059	5	-6	NS	-0.70	NS	-0.04	NS	10	S(5%)	2	NS	8	NS
27001	7	-19	S(1%)	-0.96	S(1%)	-0.03	NS	15	NS	1	S(5%)	7	S(1%)
27002	11	2	NS	0.09	NS	0.00	NS	42.5	S(5%)	6	NS	38.5	NS
27003	10	-21	S(10%	) -0.697	S(5%)	-0.02	NS	27	NS	4	NS	21.5	S(5%)
27070	6	-3	NS	-0.43	NS	-0.07	NS	10	NS	3	NS	10	NS
29001	9	21	S(5%)	0.76	S(5%)	0.04	NS	37.5	S(1%)	5	NS	19.5	NS
29004	7	7	NS	0.50	NS	0.01	NS	21	S(1%)	4	NS	13	NS
29011	5	6	NS	0.80	NS	0.05	NS	13	S(1%)	3	NS	7	NS
29071	6	7	NS	0.60	NS	0.03	NS	16	S(5%)	4	NS	14	NS
30001	11	-21	NS	-0.56	S(5%)	-0.04	NS	28	NS	8	NS	30	NS
30004	9	16	NS	0.57	S(10%)	0.07	S(10%)	33	S(1%)	4	NS	22	NS
30005	10	13	NS	0.58	S(5%)	0.06	S(5%)	43	S(1%)	3	S(10%)	18	S(1%)
30007	7	2	NS	0.08	NS	0.01	S(5%)	23	S(1%)	2	NS	12	NS
31002	6	7	NS	0.71	NS	0.03	NS	17	S(1%)	3	NS	9	NS
32012	5	0	NS	0.10	NS	-0.01	NS	11	S(1%)	3	NS	9	NS
33070	6	-1	NS	-0.09	NS	-0.01	NS	16	S(5%)	1	S(10%)	9	NS
34001	8	14	NS	0.62	S(10%)	0.03	NS	30	S(1%)	2	S(10%)	12	S(5%)
34003	6	-1	NS	0.03	NS	0.00	NS	15	S(5%)	3	NS	11	NS
34009	7	1	NS	0.00	NS	0.00	NS	20	S(1%)	5	S(10%)	20	NS
34011	6	5	NS	0.37	NS	0.02	NS	16	S(5%)	3	NS	14	NS
34018	6	7	NS	0.71	S(10%)	0.06	NS	16	S(5%)	3	NS	10	NS
34024	6	3	NS	0.31	NS	0.01	NS	16	S(5%)	3	NS	14	NS
35001	7	-15	S(5%)	-0.79	S(5%)	-0.08	NS	18	S(10%)	2	NS	12	NS
35002	7	11	NS	0.75	S(5%)	0.03	S(10%)	23	S(1%)	4	NS	13	NS
35005	12	38	S(5%)	0.77	S(1%)	0.03	NS	57	S(1%)	6	NS	33	S(10%)
35071	7	0	NS	-0.12	NS	0.00	S(10%)	20	S(1%)	2	NS	15	NS
35073	6	3	NS	0.31	NS	0.02	NS	16	S(5%)	3	NS	11	NS
36010	10	9	NS	0.15	NS	0.01	NS	33	NS	4	NS	33	NS
36011	10	33	S(1%)	0.82	S(1%)	0.03	NS	41	S(1%)	2	S(1%)	19	S(5%)
36012	10	32	S(1%)	0.85	S(1%)	0.04	NS	43.5	S(1%)	6	NS	23	S(10%)
36015	7	11	NS	0.68	S(10%)	0.04	S(10%)	24	S(1%)	4	NS	16	NS
36018	10	17	NS	0.58	S(5%)	0.02	NS	37.5	S(5%)	4	NS	19.5	S(5%)
36019	10	23	S(5%)	0.61	S(5%)	0.03	NS	38	S(5%)	4	NS	23	S(10%)
36021	6	-1	NS	-0.20	NS	0.00	NS	14	NS	3	NS	15	NS

Table 6.2: Trend test results (Median Series)

STATION	Record Length (years)	Mann-Kendall		Spearman's Rho		Linear Regression		Mann Whitney U Test		Turning Point Test		Rank Diff. Test	
		Test Statistic (S)	Result	Test Statistic (D)	Result	Test Statistic (b_s)	Result	Test Statistic (U)	Result	Test Statistic (N)	Result	Test Statistic (U)	Result
36027	4	-2	NS	-0.40	NS	-0.02	NS	6	NS	2	NS	6	NS
36031	6	8	NS	0.61	NS	0.02	NS	17.5	S(1%)	2	NS	11	NS
39008	7	1	NS	0.04	NS	0.02	NS	22	S(1%)	4	NS	16	NS
39009	7	5	NS	0.14	NS	0.01	NS	23	S(1%)	2	NS	12	NS

**S/5% denotes that test statistic is significant at the 5% significance level*

Table 6.3: Summary of trend test results (for both data scenarios)

STATION	Mann-Kendall		Spearman's Rho		MW- Linear Regression		Mann Whittney U test		Turning Point		Rank Difference	
	AM Series	Median Series	AM Series	Median Series	AM Series	Median Series	AM Series	Median Series	AM Series	Median Series	AM Series	Median Series
6011	NS	NS	NS	NS	NS	NS	NS	S(5%)	NS	NS	NS	NS
6013	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
6014	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	S(5%)
6025	S(5%)	S(5%)	S(5%)	S(5%)	NS	NS	S(1%)	S(1%)	NS	NS	NS	NS
6026	NS	NS	NS	NS	S(5%)	NS	NS	NS	NS	NS	NS	NS
6031	-	NS	-	NS	-	NS	-	S(1%)	-	NS	-	NS
7002	-	NS	-	NS	-	NS	-	S(1%)	-	NS	-	NS
7003	-	S(5%)	-	S(1%)	-	NS	-	S(1%)	-	S(10%)	-	S(1%)
7004	-	S(5%)	-	S(5%)	-	S(1%)	-	S(1%)	-	NS	-	S(10%)
7005	-	NS	-	NS	-	S(10%)	-	S(1%)	-	NS	-	NS
7006	NS	NS	NS	NS	NS	NS	NS	S(5%)	NS	NS	NS	S(5%)
7007	-	NS	-	NS	-	NS	-	S(5%)	-	NS	-	NS
7009	NS	NS	NS	NS	NS	NS	S(5%)	NS	NS	NS	NS	NS
7010	-	S(1%)	-	S(1%)	-	NS	-	S(1%)	-	NS	-	S(1%)
7011	-	S(1%)	-	S(1%)	-	S(1%)	-	S(1%)	-	NS	-	S(1%)
7012	-	S(5%)	-	S(5%)	-	S(1%)	-	S(1%)	-	NS	-	NS
7033	NS	NS	NS	NS	NS	S(1%)	S(10%)	S(1%)	NS	NS	NS	NS
8002	NS	NS	NS	NS	NS	NS	S(10%)	NS	NS	NS	NS	NS
8008	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS
9001	NS	NS	NS	NS	NS	S(1%)	NS	NS	NS	NS	NS	NS
9002	NS	NS	NS	NS	S(1%)	NS	NS	S(1%)	NS	NS	NS	NS
9010	-	NS	-	NS	-	S(5%)	-	NS	-	NS	-	NS
10021	NS	NS	NS	NS	NS	NS	S(1%)	S(1%)	NS	NS	NS	NS
11001	NS	NS	NS	NS	NS	NS	NS	S(1%)	NS	NS	NS	NS
14005	-	S(5%)	-	S(1%)	-	NS	-	NS	-	NS	-	S(10%)
14006	NS	NS	NS	NS	NS	S(10%)	NS	NS	NS	NS	NS	NS
14009	S(10%)	S(10%	S(10%)	S(5%)	NS	S(10%)	NS	S(5%)	NS	NS	NS	NS
14013	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
14018	S(10%)	NS	S(10%)	NS	NS	NS	S(5%)	S(5%)	NS	NS	NS	NS
14019	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
14029	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS
14034	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
15003	NS	NS	NS	NS	NS	NS	S(10%)	NS	NS	NS	NS	NS
15004	S(1%)	S(5%)	S(1%)	S(5%)	S(1%)	NS	S(1%)	S(1%)	S(5%)	NS	S(5%)	S(1%)
16002	NS	S(10%	NS	S(5%)	S(10%)	S(10%)	NS	NS	NS	NS	NS	NS
16003	S(1%)	S(1%)	S(1%)	S(1%)	S(1%)	NS	S(1%)	S(1%)	NS	NS	S(1%)	S(1%)
16004	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
16005	NS	NS	NS	NS	NS	NS	NS	S(5%)	NS	NS	NS	NS
16008	S(5%)	NS	S(5%)	NS	NS	NS	S(1%)	S(5%)	NS	NS	NS	NS

Table 6.3: Summary of trend test results (for both data scenarios)

STATION	Mann-Kendall		Spearman's Rho		MW- Linear Regression		Mann Whittney U test		Turning Point		Rank Difference	
	AM Series	Median Series	AM Series	Median Series	AM Series	Median Series	AM Series	Median Series	AM Series	Median Series	AM Series	Median Series
16009	S(10%)	NS	S(10%)	NS	NS	NS	S(5%)	S(1%)	NS	NS	NS	NS
18005	NS	NS	NS	S(5%)	NS	NS	S(5%)	S(1%)	NS	NS	NS	NS
19001	NS	NS	NS	NS	NS	NS	NS	S(5%)	NS	NS	NS	NS
19020	S(10%)	S(10%	S(10%)	S(5%)	S(5%)	NS	NS	NS	NS	NS	NS	S(5%)
23001	NS	NS	NS	NS	NS	S(10%)	S(5%)	S(10%)	NS	NS	NS	NS
23002	-	NS	-	NS	-	NS	-	S(5%)	-	NS	-	NS
23012	S(10%)	NS	S(5%)	NS	NS	NS	S(1%)	S(1%)	S(1%)	NS	S(1%)	NS
24001	S(1%)	S(10%	S(1%)	S(5%)	S(1%)	NS	S(1%)	S(1%)	NS	NS	S(1%)	S(10%)
24008	NS	NS	NS	NS	NS	S(10%)	NS	S(5%)	NS	NS	NS	NS
24013	-	S(1%)	-	S(1%)	-	NS	-	S(1%)	-	NS	-	S(10%)
24022	S(5%)	NS	S(5%)	NS	S(1%)	S(1%)	S(1%)	S(5%)	NS	NS	NS	NS
24082	S(5%)	NS	S(5%)	NS	S(5%)	NS	S(10%)	S(1%)	NS	NS	NS	NS
25001	-	S(1%)	-	S(1%)	-	NS	-	NS	-	NS	-	S(1%)
25002	S(1%)	S(10%	S(1%)	S(5%)	NS	NS	S(5%)	NS	NS	NS	S(5%)	NS
25003	S(1%)	S(5%)	S(1%)	S(1%)	NS	NS	S(10%)	NS	S(5%)	NS	NS	S(10%)
25005	-	NS	-	NS	-	NS	-	S(5%)	-	NS	-	NS
25006	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
25014	S(1%)	S(5%)	S(1%)	S(5%)	S(1%)	NS	S(5%)	NS	NS	NS	S(1%)	NS
25017	NS	S(10%	NS	S(5%)	NS	NS	S(5%)	S(1%)	NS	NS	NS	NS
25021	S(5%)	S(5%)	S(5%)	S(1%)	NS	NS	S(1%)	S(1%)	NS	NS	NS	S(1%)
25023	S(1%)	NS	S(1%)	S(5%)	S(1%)	NS	S(1%)	S(1%)	NS	NS	S(5%)	S(10%)
25025	-	NS	-	NS	-	S(10%)	-	S(1%)	-	NS	-	NS
25027	NS	NS	NS	NS	NS	NS	S(1%)	S(5%)	NS	NS	NS	NS
25029	S(1%)	NS	S(1%)	NS	S(5%)	NS	S(1%)	S(1%)	NS	NS	S(10%)	NS
25030	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
25044	-	NS	-	NS	-	NS	-	S(5%)	-	NS	-	NS
25158	S(10%)	NS	NS	NS	NS	NS	S(5%)	NS	NS	NS	NS	NS
26002	NS	NS	NS	NS	NS	NS	NS	S(10%)	NS	S(5%)	NS	S(10%)
26005	S(1%)	NS	S(1%)	NS	NS	NS	S(1%)	S(10%)	NS	NS	NS	NS
26006	NS	NS	NS	NS	NS	NS	S(10%)	NS	S(1%)	NS	NS	NS
26007	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
26008	S(5%)	NS	S(10%)	NS	NS	NS	S(5%)	NS	S(10%)	NS	S(10%)	NS
26009	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
26012	-	S(1%)	-	S(1%)	-	NS	-	S(1%)	-	S(10%)	-	S(1%)
26017	NS	NS	NS	NS	NS	S(1%)	S(10%)	NS	S(10%)	S(10%)	NS	S(10%)
26018	NS	NS	NS	NS	NS	NS	S(10%)	NS	NS	S(1%)	NS	S(10%)
26019	S(5%)	NS	S(10%)	S(10%)	NS	NS	NS	NS	NS	NS	NS	NS
26020	NS	NS	NS	NS	NS	NS	S(1%)	S(1%)	NS	NS	NS	NS
26021	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
26022	NS	NS	NS	S(10%)	NS	NS	NS	S(5%)	NS	NS	NS	S(5%)
26059	S(5%)	NS	S(5%)	NS	NS	NS	NS	S(5%)	NS	NS	NS	NS
27001	S(5%)	S(1%)	S(5%)	S(1%)	NS	NS	S(10%)	NS	NS	S(5%)	NS	S(1%)
27002	NS	NS	NS	NS	NS	NS	S(10%)	S(5%)	NS	NS	NS	NS
27003	NS	S(10%	NS	S(5%)	NS	NS	NS	NS	NS	NS	NS	S(5%)
27070	NS	NS	NS	NS	S(5%)	NS	NS	NS	S(1%)	NS	S(1%)	NS
29001	-	S(5%)	-	S(5%)	-	NS	-	S(1%)	-	NS	-	NS
29004	NS	NS	NS	NS	NS	NS	S(10%)	S(1%)	S(5%)	NS	NS	NS
29011	S(10%)	NS	S(10%)	NS	S(5%)	NS	S(5%)	S(1%)	NS	NS	NS	NS
29071	S(10%)	NS	S(5%)	NS	NS	NS	S(1%)	S(5%)	NS	NS	NS	NS
30001	-	NS	-	S(5%)	-	NS	-	NS	-	NS	-	NS
30004	-	NS	-	S(10%)	-	S(10%)	-	S(1%)	-	NS	-	NS
30005	-	NS	-	S(5%)	-	S(5%)	-	S(1%)	-	S(10%)	-	S(1%)

Table 6.3: Summary of trend test results (for both data scenarios)

STATION	Mann-Kendall		Spearman's Rho		MW- Linear Regression		Mann Whittney U test		Turning Point		Rank Difference	
	AM Series	Median Series	AM Series	Median Series	AM Series	Median Series	AM Series	Median Series	AM Series	Median Series	AM Series	Median Series
30007	NS	NS	NS	NS	NS	S(5%)	NS	S(1%)	NS	NS	NS	NS
31002	NS	NS	NS	NS	NS	NS	NS	S(1%)	S(10%)	NS	S(10%)	NS
32012	NS	NS	NS	NS	NS	NS	NS	S(1%)	NS	NS	NS	NS
33070	NS	NS	NS	NS	NS	NS	S(1%)	S(5%)	NS	S(10%)	S(10%)	NS
34001	S(5%)	NS	S(5%)	S(10%)	NS	NS	S(1%)	S(1%)	NS	S(10%)	NS	S(5%)
34003	NS	NS	NS	NS	NS	NS	S(5%)	S(5%)	NS	NS	NS	NS
34009	NS	NS	NS	NS	NS	NS	NS	S(1%)	S(5%)	S(10%)	S(10%)	NS
34011	NS	NS	NS	NS	NS	NS	NS	S(5%)	NS	NS	S(1%)	NS
34018	S(1%)	NS	S(1%)	S(10%)	S(10%)	NS	S(1%)	S(5%)	NS	NS	NS	NS
34024	NS	NS	NS	NS	NS	NS	NS	S(5%)	NS	NS	NS	NS
35001	NS	S(5%)	NS	S(5%)	NS	NS	NS	S(10%)	S(1%)	NS	S(5%)	NS
35002	NS	NS	NS	S(5%)	NS	S(10%)	NS	S(1%)	NS	NS	NS	NS
35005	-	S(5%)	-	S(1%)	-	NS	-	S(1%)	-	NS	-	S(10%)
35071	NS	NS	NS	NS	NS	S(10%)	S(5%)	S(1%)	NS	NS	NS	NS
35073	NS	NS	NS	NS	NS	NS	NS	S(5%)	NS	NS	NS	NS
36010	NS	NS	NS	NS	NS	NS	S(5%)	NS	NS	NS	S(5%)	NS
36011	S(1%)	S(1%)	S(1%)	S(1%)	S(10%)	NS	S(1%)	S(1%)	NS	S(1%)	S(5%)	S(5%)
36012	S(5%)	S(1%)	S(1%)	S(1%)	S(5%)	NS	S(1%)	S(1%)	S(10%)	NS	S(1%)	S(10%)
36015	S(5%)	NS	S(5%)	S(10%)	S(10%)	S(10%)	S(1%)	S(1%)	NS	NS	NS	NS
36018	S(5%)	NS	S(5%)	S(5%)	NS	NS	S(5%)	S(5%)	NS	NS	NS	S(5%)
36019	S(5%)	S(5%)	S(5%)	S(5%)	NS	NS	S(1%)	S(5%)	NS	NS	S(1%)	S(10%)
36021	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
36027	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS
36031	NS	NS	NS	NS	NS	NS	NS	S(1%)	NS	NS	NS	NS
39008	NS	NS	NS	NS	NS	NS	NS	S(1%)	NS	NS	NS	NS
39009	NS	NS	NS	NS	NS	NS	NS	S(1%)	NS	NS	NS	NS

*S/5% denotes that test statistic is significant at 5% significance level

6.4 The number of times the null hypothesis is rejected in the records taking each test in turn is summarised in **Tables 6.4 & 6.5** below for the data scenarios 1 & 2 respectively.

Table 6.4: Number of cases in which the null hypothesis is rejected at stated level out of 91 cases (Scenario 1 – Full Records)

Sing. Level	Trend and persistence			Split sample test	Randomness test	
	Mann-Kendall	Spearman Rho	Mean-weighted Linear Regressn.	Mann Whitney U test	Turning point	Rank difference
1%	11	12	7	22	4	8
5%	25	25	14	36	8	14

Table 6.5: Number of cases in which the null hypothesis is rejected at stated level out of 117 cases (Scenario 2 – Median Series)						
Sing. Level	Trend and persistence			Split sample test	Randomness test	
	Mann-Kendall	Spearman Rho	Mean-weighted Linear Regressn.	Mann Whitney U test	Turning point	Rank difference
1%	9	14	7	47	2	10
5%	22	35	10	73	4	18

6.5 In the trend tests, out of 91 records, 25 (27.47%) show statistically significant trends 12 at the 1% level, and an additional 13 at the 5% level - Spearman Rho test) in the case Scenario 1, while 35 series out of 117 (29.91%) in the Scenario 2 Median Series (14 at the 1% level and a further 21 at the 5% level). The specially derived parametric linear regression test found only about half as many stations to be significant as the other two. All the tests show a strong evidence of upward trend in both Scenarios.

6.6 The tests for randomness & independence identified non-randomness in approximately 15% of the Annual Maximum series. Out of 91 AM series, 14 show significant non-randomness (8 at the level of 1% and a further 6 at the level of 5%) in the AM Series. While in the case of Median Series, 18 time series out of 117 (15%) show significant non-randomness (10 at the level of 1% and a further 8 at the level of 5%).

Stations with any one test indicating significance at the 1% level are highlighted in green in **Tables 6.1 & 6.2**.

6.7 Looking at the individual records the following stations show the most marked departures from the null hypothesis of zero trend.

Scenario 1 - AM Series (stations significant at 1% significance level)

Station	Location	Results
15004	Nore at Mcmahons Br.	Increase
16003	Clodiagh at Rathkennan	Increase
24001	Maigue at Croom	Increase
25002	Newport at Barrington's Br.	Decrease
25003	Mulkear at Abington	Decrease
25014	Silver at Millbrook	Decrease
25023	Little Brosna at Milltown	Increase
25029	Nenagh at Clarianna	Increase
26005	Suck at Derrycahill	Increase
34018	Castlebar at Turlough	Increase
36011	Erne at Bellahillan	Increase

Scenario 2 - Median Series (stations significant at 1% significance level)

Station	Locations	Results
7010	Blackwater (Kells) at Liscarton	Increase
7011	Blackwater (Kells) at O'Daly's Br.	Increase
16003	Clodiagh at Rathkennan	Increase
24013	Deel at Rathkeale	Increase
25001	Mulkear at Annacotty	Decrease
26012	Boyle at Tinacarra	Increase
27001	Claureen at Inch Br.	Decrease
36011	Erne at Bellahillan	Increase
36012	Erne at Sallaghan	Increase

The graphical plots of the above AM Flow Series are shown in **Figure 5.1.**

6.7 Based on the above, the possibility of trend in the Irish Annual Maximum Flood Series cannot be dismissed. Besides hydrometric reasons such as rating curve uncertainties and weir changes, there are of course possible hydrological reasons for trend based on land use changes such as hydroelectric development, channel improvements and land drainage, and more importantly climate change.

6.8 It is important to examine the test results alongside graphs of the data, and with as much historical knowledge about the data as possible (Kundzewicz & Robson, 2004).

6.9 The impact of drainage works on the AM Flows at 16 stations were identified through EDA as discussed previously. An abrupt change in the AM flows at most of these stations occurred at the beginning of the post drainage stage. Refer to **Figure 5.2** for the graphical plots of the AM Flows for these stations. In the case where drainage works are not an issue but significant trend is identified, further examination of records should be carried out in order to find out the factors causing trends in the AM Flow.

6.9 In order to investigate the possible impact of climate change on the AM Flood flows in the Irish Rivers, a further examination of some of the selected AM flows series (listed below) in which significant trends were detected have been carried out. The available flow records for these stations have been split into two halves and were plotted in two graphs as shown in **Figure 6.1** below. 3 out of 5 Annual Maximum Flow Series show a slight increase in trend in the later halves of their records. No drainage improvement works were reported to be carried out in any of these catchments.

Station	Location
15004	Nore at McMahons Br.
16008	Suir at Newbridge
25003	Mulkear at Abington
25014	Silver at Millbrook
26005	Suck at Derrycahill

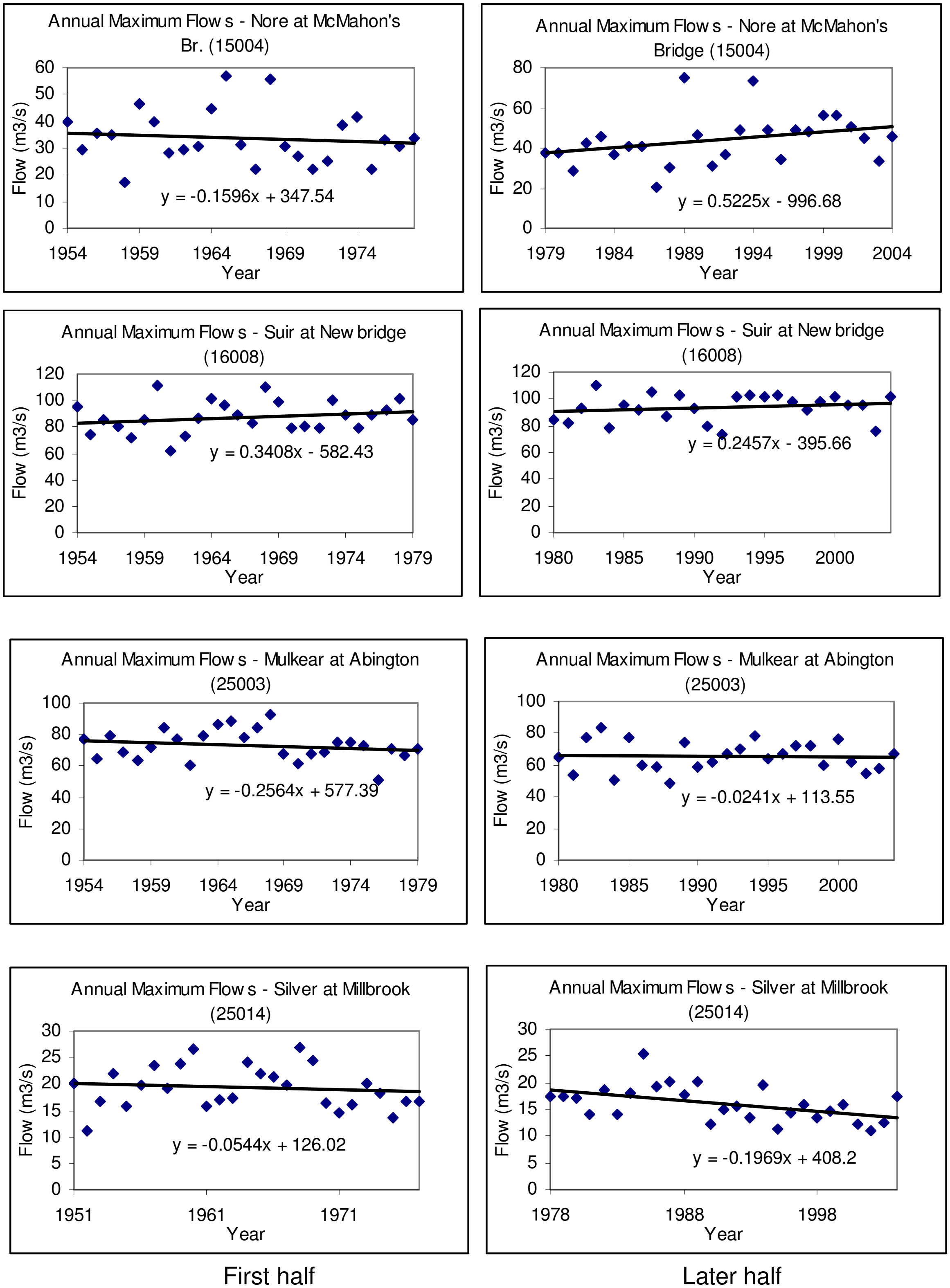
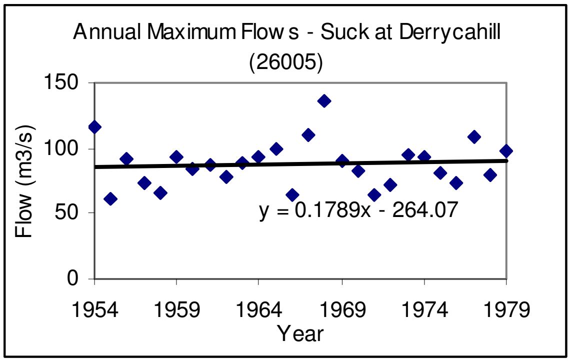
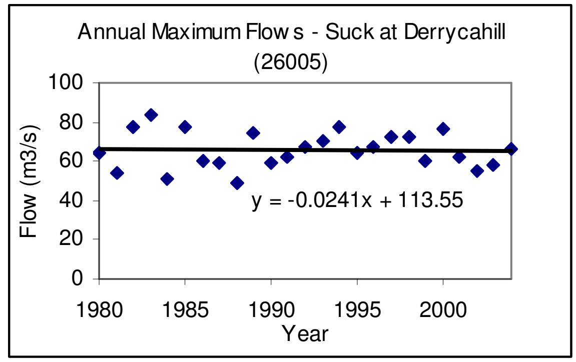


Figure 6.1: Plots of Annual Maximum Flows (examination of climate change impact)



First half



Later half

Figure 6.1: Plots of Annual Maximum Flows (examination of climate change impact)

7.0 Conclusions and Recommendations

7.1 In order to detect the trend and/or other non-randomness nature in the Annual Maximum Flood Series of Irish Rivers, 6 statistical tests were applied to 117 Annual Maximum Flood Series and also to the derived 5 yearly Median Series.

7.2 Distribution-free statistical tests are considered to be appropriate in detecting trends in the Annual Maximum Flood Series in Ireland because of the non-normal nature (EV1) of the flow series.

7.3 An EV1 distribution based Mean-weighted Linear Regression Trend test method was developed especially for this study. Critical values for the test statistic were obtained by simulation from the sampling distribution. This test found only about 50% as many records rejecting the null hypothesis as the other non parametric trend tests for trend (Mann-Kendall and Spearman's Rho)

7.4 The trend tests showed a strong evidence of upward trend (both gradual and abrupt) in the Annual Maximum Flow Series in Ireland. Out of 91 records, 25 (27.5%) show statistically significant trends (12 at the 1% level and a further 13 at the 5% level - Spearman Rho test) in the case of AM Series data scenario, with 35 series out of 117 (30%) in the Median Series data scenario (14 at the 1% level and a further 21 at the 5% level).

7.5 The tests for independence identified non-randomness in approximately 15% of the annual maximum series. Out of 91 AM series, 14 show significant non-randomness (8 at the level of 1% and a further 6 at the level of 5% in the AM Series) while 18 time series out of 117 (15%) show significant non-randomness in the Median Series (10 at the level of 1% and a further 8 at the level of 5%).

7.7 The impact of climate change on the trend or other changes in the Annual Maximum Flood series in Ireland was found to be insignificant.

7.8 In the cases where drainage works are not an issue but significant trend is evident, further examination of records should be carried out in order to find out the factors causing the trends in the AM Flows.

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APPENDIX A2

CRITICAL VALUES FOR THE LINEAR REGRESSION BASED TEST STATISTIC FOR TREND ASSUMING EV1 DISTRIBUTION OF MAGNITUDES.

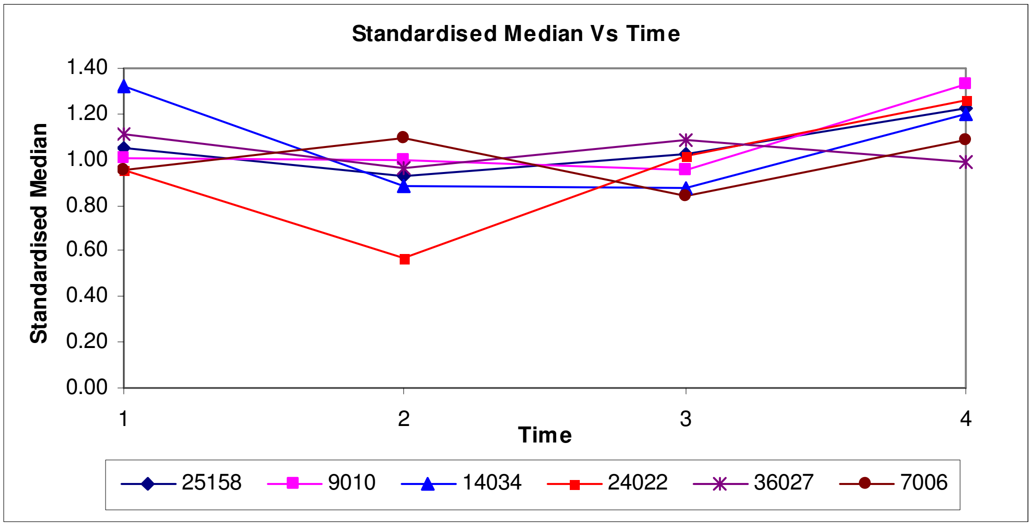
(STATISTICAL TABLE)

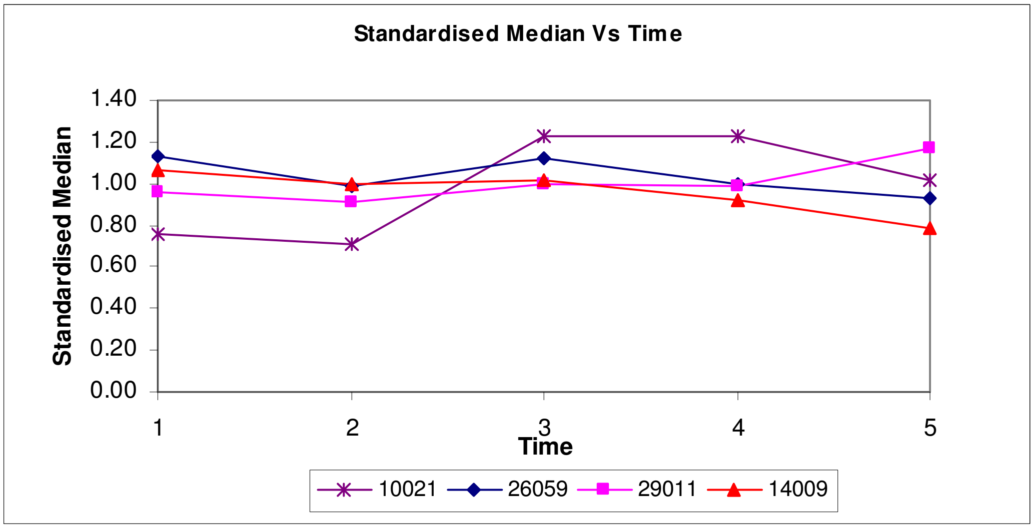
N	BSMIN	BSBEAN	BSMAX	BScritical										STDEVBS	SKEWBS
				α=0.005	α=0.01	α=0.025	α=0.05	α=0.10	α=0.90	α=0.95	α=0.975	α=0.99	α=0.995		
3	-0.7937	-0.0024	0.8339	-0.5247	-0.4742	-0.3993	-0.3388	-0.2593	0.2528	0.3250	0.3949	0.4724	0.5221	0.2015	0.0064
4	-0.4688	0.0002	0.5260	-0.3360	-0.3018	-0.2585	-0.2104	-0.1634	0.1629	0.2083	0.2489	0.2995	0.3364	0.1281	0.0027
5	-0.4118	0.0002	0.3330	-0.2323	-0.2109	-0.1794	-0.1482	-0.1144	0.1162	0.1497	0.1793	0.2171	0.2422	0.0906	0.0178
6	-0.2562	-0.0011	0.2760	-0.1822	-0.1662	-0.1387	-0.1182	-0.0909	0.0879	0.1142	0.1367	0.1631	0.1815	0.0699	0.0097
7	-0.2389	0.0003	0.2282	-0.1434	-0.1321	-0.1106	-0.0921	-0.0699	0.0702	0.0921	0.1094	0.1298	0.1417	0.0554	-0.0355
8	-0.1956	0.0005	0.1563	-0.1184	-0.1053	-0.0885	-0.0744	-0.0567	0.0575	0.0752	0.0884	0.1047	0.1186	0.0450	-0.0211
9	-0.1526	-0.0006	0.1353	-0.1004	-0.0910	-0.0756	-0.0633	-0.0490	0.0474	0.0612	0.0738	0.0886	0.0986	0.0378	-0.0260
10	-0.1218	-0.0006	0.1321	-0.0832	-0.0765	-0.0655	-0.0540	-0.0420	0.0405	0.0529	0.0632	0.0761	0.0872	0.0325	0.0347
11	-0.1178	0.0003	0.1063	-0.0737	-0.0666	-0.0558	-0.0460	-0.0350	0.0369	0.0471	0.0565	0.0672	0.0741	0.0282	0.0303
12	-0.1312	-0.0004	0.0969	-0.0639	-0.0584	-0.0488	-0.0410	-0.0316	0.0307	0.0398	0.0474	0.0561	0.0623	0.0245	-0.0364
13	-0.0857	-0.0001	0.0781	-0.0578	-0.0513	-0.0427	-0.0352	-0.0278	0.0276	0.0352	0.0433	0.0504	0.0571	0.0217	0.0066
14	-0.0786	0.0003	0.0751	-0.0514	-0.0454	-0.0377	-0.0319	-0.0248	0.0254	0.0325	0.0384	0.0470	0.0516	0.0196	-0.0033
15	-0.0782	0.0002	0.0610	-0.0456	-0.0403	-0.0344	-0.0290	-0.0221	0.0229	0.0292	0.0342	0.0404	0.0459	0.0176	-0.0189
16	-0.0603	0.0001	0.0547	-0.0404	-0.0365	-0.0308	-0.0255	-0.0197	0.0201	0.0256	0.0304	0.0355	0.0388	0.0154	-0.0354
17	-0.0628	-0.0001	0.0551	-0.0378	-0.0344	-0.0281	-0.0237	-0.0183	0.0181	0.0230	0.0274	0.0328	0.0362	0.0142	-0.0435
18	-0.0575	0.0001	0.0549	-0.0328	-0.0308	-0.0257	-0.0216	-0.0166	0.0168	0.0219	0.0262	0.0311	0.0348	0.0132	0.0412
19	-0.0457	0.0000	0.0468	-0.0310	-0.0280	-0.0236	-0.0197	-0.0156	0.0155	0.0200	0.0237	0.0279	0.0311	0.0120	0.0209
20	-0.0420	0.0002	0.0418	-0.0302	-0.0269	-0.0219	-0.0182	-0.0141	0.0146	0.0186	0.0217	0.0257	0.0287	0.0112	-0.0403
21	-0.0432	0.0000	0.0412	-0.0270	-0.0244	-0.0203	-0.0174	-0.0134	0.0135	0.0173	0.0204	0.0239	0.0267	0.0104	-0.0144
22	-0.0361	0.0000	0.0432	-0.0255	-0.0235	-0.0189	-0.0158	-0.0120	0.0123	0.0162	0.0196	0.0232	0.0256	0.0097	0.0424
23	-0.0315	0.0000	0.0345	-0.0235	-0.0213	-0.0180	-0.0151	-0.0118	0.0117	0.0149	0.0176	0.0209	0.0232	0.0091	-0.0143
24	-0.0316	-0.0001	0.0322	-0.0226	-0.0203	-0.0170	-0.0144	-0.0115	0.0110	0.0140	0.0167	0.0199	0.0220	0.0087	-0.0217
25	-0.0342	0.0000	0.0291	-0.0214	-0.0193	-0.0158	-0.0132	-0.0103	0.0104	0.0133	0.0160	0.0190	0.0215	0.0081	0.0027
26	-0.0286	0.0001	0.0284	-0.0192	-0.0171	-0.0144	-0.0122	-0.0095	0.0097	0.0123	0.0149	0.0179	0.0201	0.0075	0.0171
27	-0.0296	0.0000	0.0309	-0.0184	-0.0167	-0.0142	-0.0119	-0.0093	0.0091	0.0117	0.0138	0.0165	0.0186	0.0072	-0.0227
28	-0.0283	0.0000	0.0328	-0.0177	-0.0157	-0.0134	-0.0112	-0.0088	0.0088	0.0111	0.0135	0.0162	0.0175	0.0068	0.0307
29	-0.0230	0.0000	0.0238	-0.0163	-0.0146	-0.0127	-0.0105	-0.0083	0.0082	0.0106	0.0126	0.0149	0.0166	0.0064	0.0120
30	-0.0247	-0.0001	0.0206	-0.0161	-0.0146	-0.0121	-0.0101	-0.0078	0.0076	0.0096	0.0116	0.0136	0.0154	0.0060	-0.0387
31	-0.0251	-0.0001	0.0190	-0.0147	-0.0134	-0.0113	-0.0094	-0.0074	0.0073	0.0094	0.0112	0.0133	0.0150	0.0057	0.0101
32	-0.0191	0.0000	0.0213	-0.0147	-0.0135	-0.0110	-0.0092	-0.0072	0.0071	0.0091	0.0108	0.0132	0.0146	0.0056	-0.0047
33	-0.0207	0.0000	0.0193	-0.0137	-0.0123	-0.0105	-0.0089	-0.0069	0.0067	0.0085	0.0103	0.0124	0.0138	0.0053	-0.0264
34	-0.0202	0.0000	0.0178	-0.0133	-0.0122	-0.0100	-0.0084	-0.0065	0.0065	0.0083	0.0100	0.0118	0.0130	0.0051	-0.0371

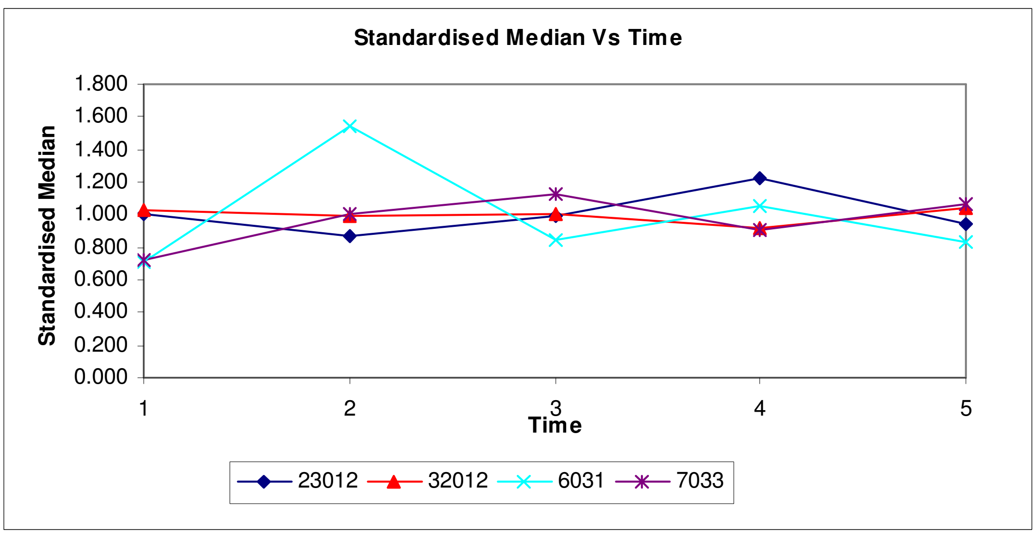
N	BSMIN	BSBEAN	BSMAX	BScritical										STDEVBS	SKEWBS
				α=0.005	α=0.01	α=0.025	α=0.05	α=0.10	α=0.90	α=0.95	α=0.975	α=0.99	α=0.995		
35	-0.0180	0.0000	0.0170	-0.0124	-0.0113	-0.0095	-0.0081	-0.0064	0.0063	0.0082	0.0098	0.0114	0.0124	0.0049	0.0375
36	-0.0178	0.0000	0.0200	-0.0124	-0.0108	-0.0091	-0.0077	-0.0060	0.0060	0.0078	0.0092	0.0110	0.0125	0.0047	0.0271
37	-0.0159	0.0000	0.0163	-0.0124	-0.0103	-0.0086	-0.0073	-0.0056	0.0057	0.0073	0.0087	0.0104	0.0114	0.0044	0.0075
38	-0.0177	0.0000	0.0160	-0.0124	-0.0101	-0.0086	-0.0071	-0.0055	0.0054	0.0069	0.0083	0.0098	0.0110	0.0043	-0.0472
39	-0.0145	-0.0001	0.0156	-0.0124	-0.0095	-0.0081	-0.0070	-0.0054	0.0053	0.0068	0.0080	0.0097	0.0110	0.0041	0.0478
40	-0.0153	0.0000	0.0154	-0.0124	-0.0090	-0.0078	-0.0065	-0.0051	0.0050	0.0065	0.0077	0.0092	0.0102	0.0040	-0.0028
41	-0.0143	0.0000	0.0163	-0.0124	-0.0090	-0.0075	-0.0063	-0.0048	0.0049	0.0064	0.0076	0.0089	0.0099	0.0038	0.0058
42	-0.0158	0.0000	0.0145	-0.0124	-0.0086	-0.0072	-0.0060	-0.0047	0.0048	0.0061	0.0073	0.0088	0.0097	0.0037	0.0098
43	-0.0150	0.0000	0.0126	-0.0124	-0.0085	-0.0072	-0.0059	-0.0046	0.0045	0.0059	0.0070	0.0083	0.0092	0.0036	-0.0121
44	-0.0136	0.0001	0.0130	-0.0124	-0.0078	-0.0067	-0.0056	-0.0044	0.0044	0.0056	0.0067	0.0080	0.0092	0.0034	0.0006
45	-0.0127	0.0000	0.0122	-0.0124	-0.0078	-0.0067	-0.0055	-0.0043	0.0043	0.0055	0.0066	0.0080	0.0089	0.0034	0.0112
46	-0.0137	0.0000	0.0112	-0.0124	-0.0075	-0.0063	-0.0054	-0.0042	0.0042	0.0053	0.0063	0.0074	0.0081	0.0032	-0.0045
47	-0.0109	0.0000	0.0120	-0.0124	-0.0072	-0.0062	-0.0053	-0.0040	0.0040	0.0051	0.0061	0.0073	0.0081	0.0031	0.0155
48	-0.0133	0.0000	0.0117	-0.0124	-0.0070	-0.0059	-0.0049	-0.0039	0.0039	0.0050	0.0060	0.0071	0.0077	0.0030	-0.0024
49	-0.0108	0.0000	0.0128	-0.0124	-0.0069	-0.0057	-0.0048	-0.0037	0.0038	0.0049	0.0058	0.0071	0.0077	0.0029	0.0328
50	-0.0123	0.0000	0.0111	-0.0124	-0.0065	-0.0055	-0.0046	-0.0035	0.0037	0.0047	0.0056	0.0068	0.0075	0.0028	0.0461
51	-0.0101	0.0000	0.0099	-0.0124	-0.0063	-0.0054	-0.0045	-0.0035	0.0036	0.0046	0.0054	0.0064	0.0071	0.0028	0.0440
52	-0.0107	0.0000	0.0093	-0.0124	-0.0061	-0.0052	-0.0044	-0.0034	0.0034	0.0044	0.0053	0.0062	0.0070	0.0027	0.0452
53	-0.0097	0.0000	0.0096	-0.0124	-0.0060	-0.0051	-0.0043	-0.0033	0.0033	0.0041	0.0049	0.0059	0.0065	0.0026	-0.0482
54	-0.0088	0.0000	0.0095	-0.0124	-0.0059	-0.0050	-0.0042	-0.0033	0.0032	0.0041	0.0049	0.0058	0.0064	0.0025	0.0171
55	-0.0096	0.0000	0.0084	-0.0124	-0.0059	-0.0049	-0.0041	-0.0032	0.0032	0.0040	0.0049	0.0058	0.0063	0.0025	-0.0466
56	-0.0090	0.0000	0.0103	-0.0124	-0.0057	-0.0048	-0.0041	-0.0031	0.0031	0.0039	0.0047	0.0056	0.0062	0.0024	-0.0030
57	-0.0082	0.0000	0.0099	-0.0124	-0.0054	-0.0046	-0.0038	-0.0030	0.0030	0.0038	0.0046	0.0054	0.0061	0.0023	0.0338
58	-0.0090	0.0000	0.0088	-0.0124	-0.0053	-0.0045	-0.0037	-0.0029	0.0030	0.0038	0.0045	0.0054	0.0059	0.0023	0.0182
59	-0.0086	0.0001	0.0090	-0.0124	-0.0051	-0.0043	-0.0036	-0.0028	0.0029	0.0037	0.0044	0.0053	0.0058	0.0022	0.0020
60	-0.0077	0.0000	0.0091	-0.0124	-0.0051	-0.0042	-0.0035	-0.0028	0.0028	0.0036	0.0043	0.0050	0.0055	0.0022	0.0349

APPENDIX A2

GRAPICAL PLOTS OF MEDIAN SERIES


Standardised Median Vs Time
Standardised Median
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1
2
3
4
Time
25158
9010
14034
24022
36027
7006


Standardised Median Vs Time
Standardised Median
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1
2
3
4
5
Time
10021
26059
29011
14009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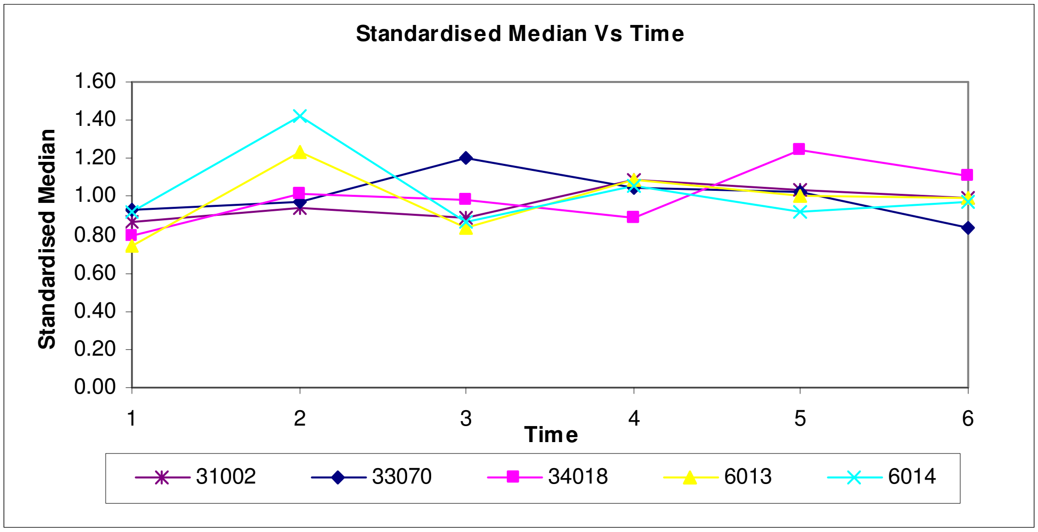
Standardised Median
1.800
1.600
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
1
2
3
4
5
Time
23012
32012
6031
7033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Standardised Median
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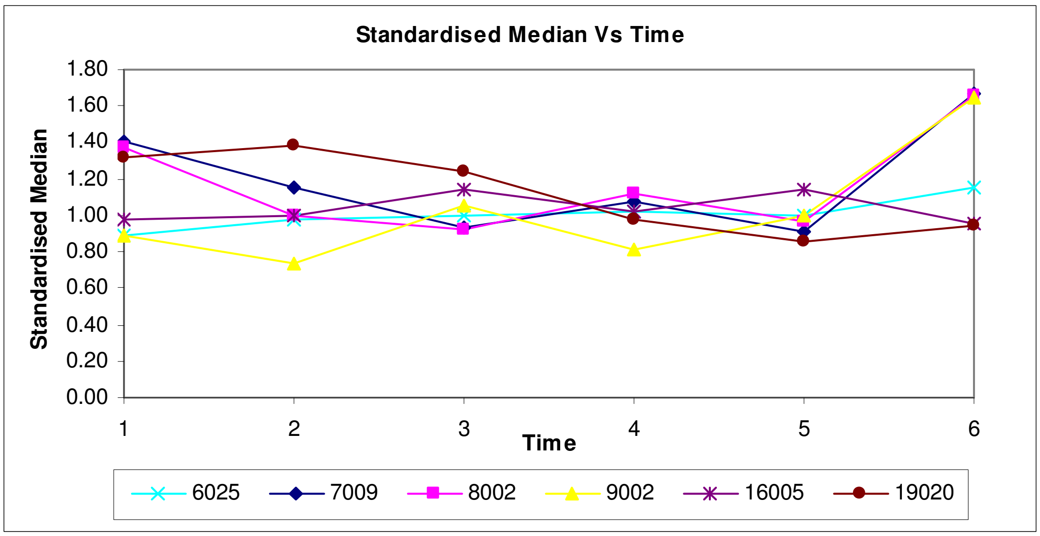
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1
2
3
4
5
6
Time
31002
33070
34018
6013
6014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1.00
0.80
0.60
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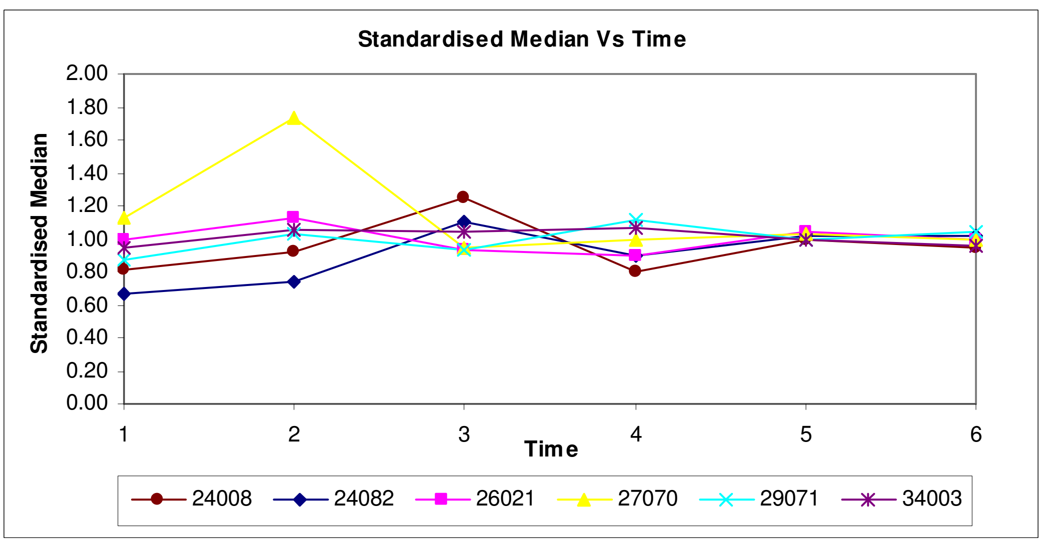
0.20
0.00
1
2
3
4
5
6
Time
6025
7009
8002
9002
16005
19020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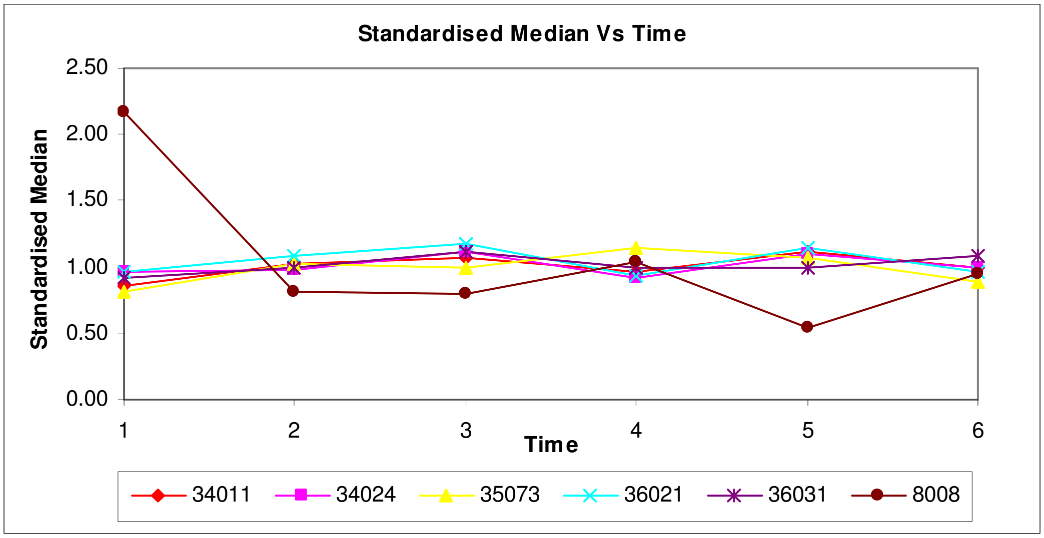
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1
2
3
4
5
6
Time
24008
24082
26021
27070
29071
34003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Time
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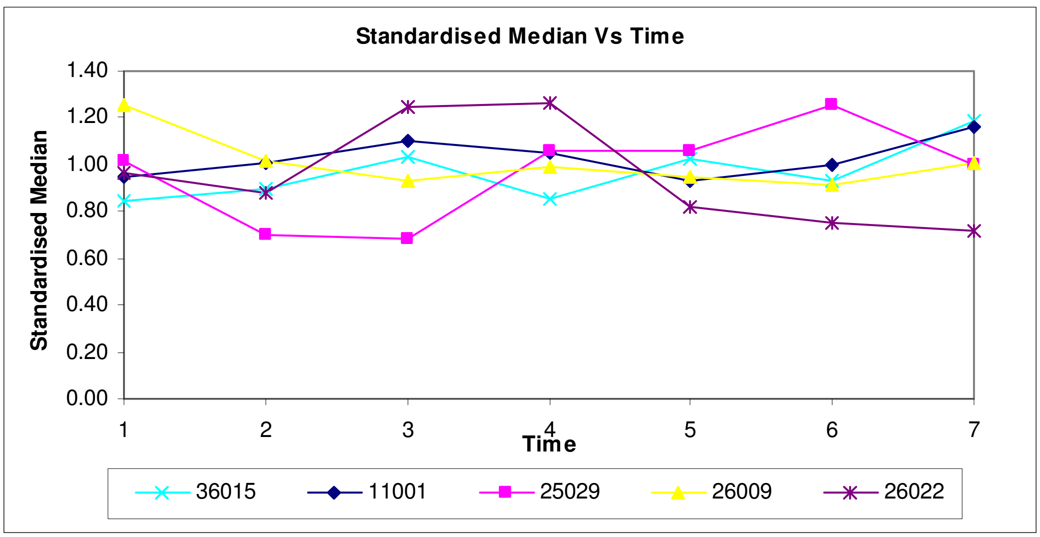
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Standardised Median
Time
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11001
25029
26009
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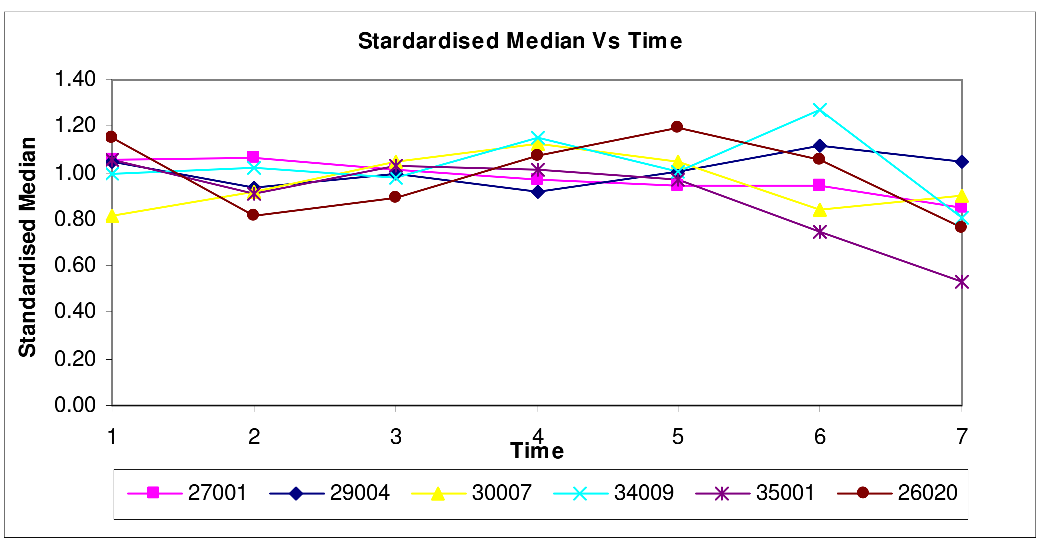
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Standardised Median
Time
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30007
34009
35001
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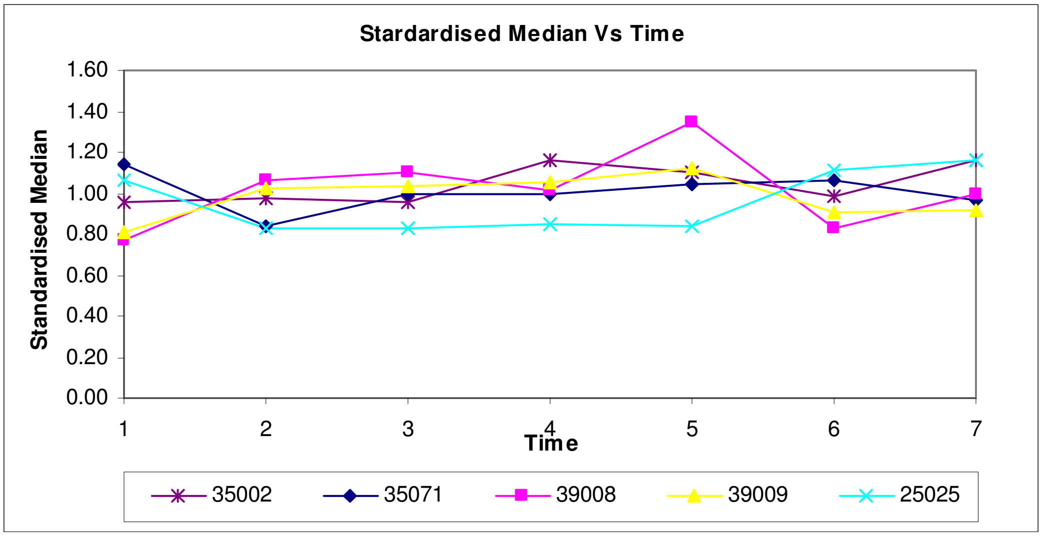
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Standardised Median
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1.20
1.00
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0.40
0.20
0.00
1 2 3 4 5 6 7
Time
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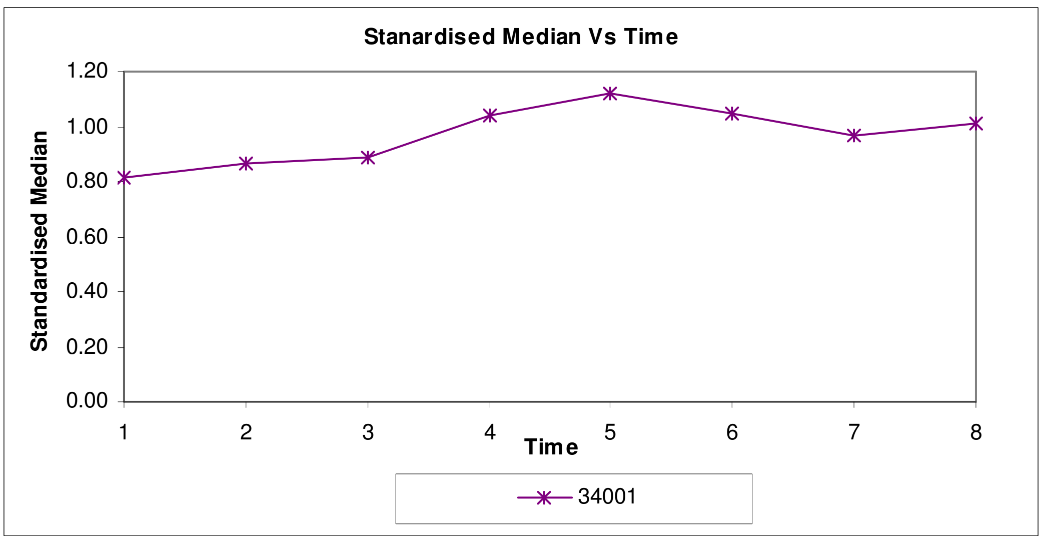
39008
39009
25025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0.00
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Time
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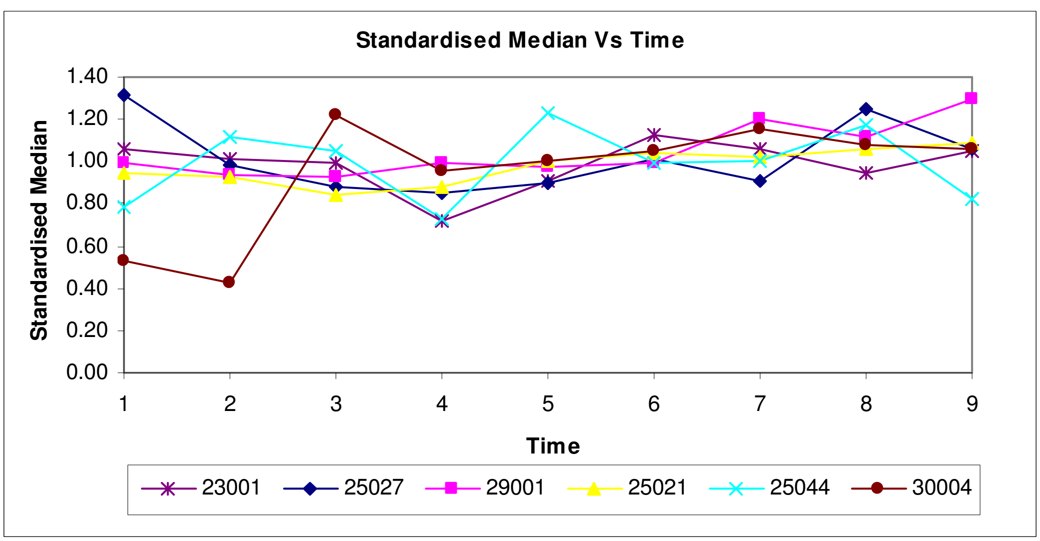
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1.00
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0.20
0.00
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Time
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25021
25044
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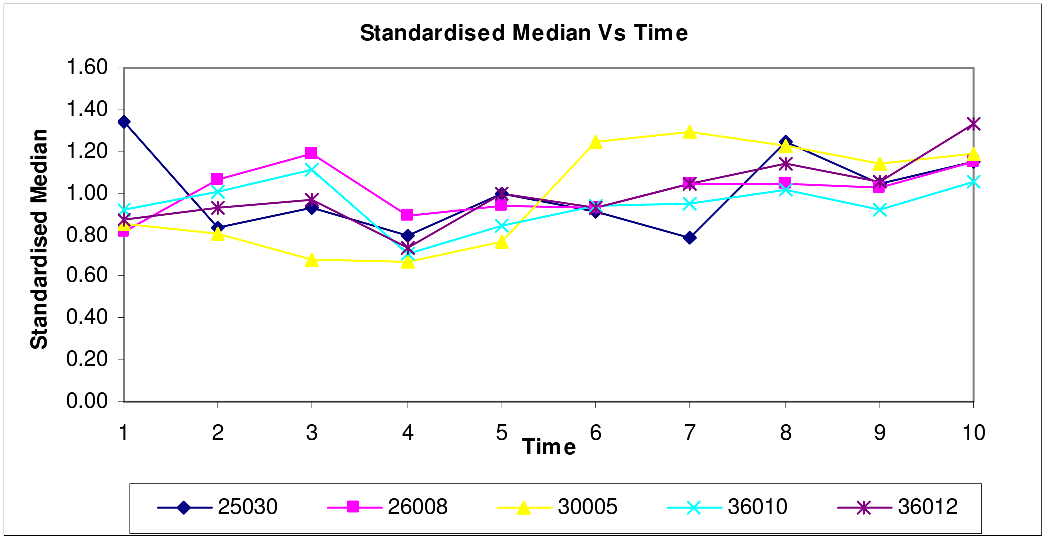
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0.40
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3
4
5
6
7
8
9
10
Time
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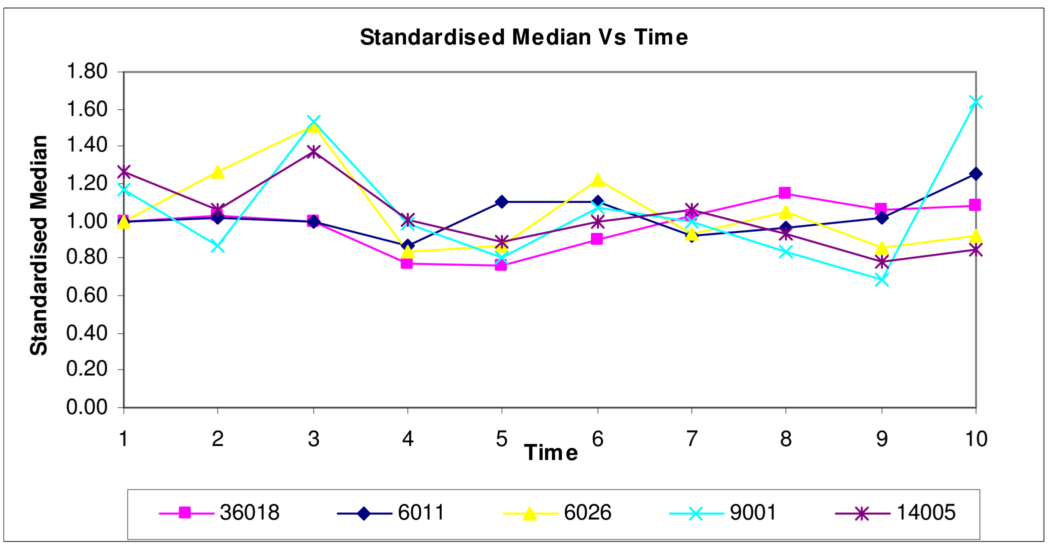
30005
36010
36012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0.40
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3
4
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6
7
8
9
10
Time
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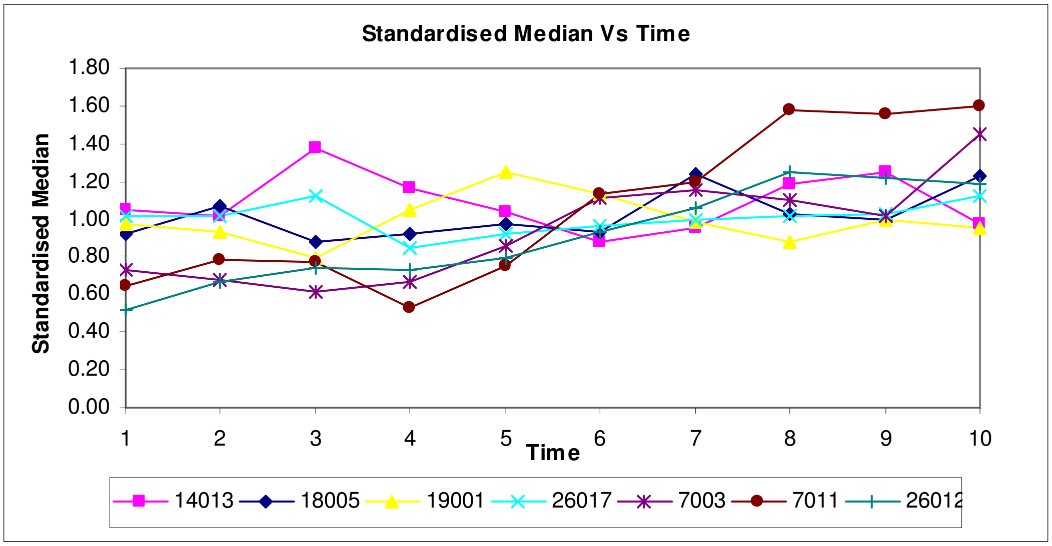
6026
9001
14005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Time
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18005
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7011
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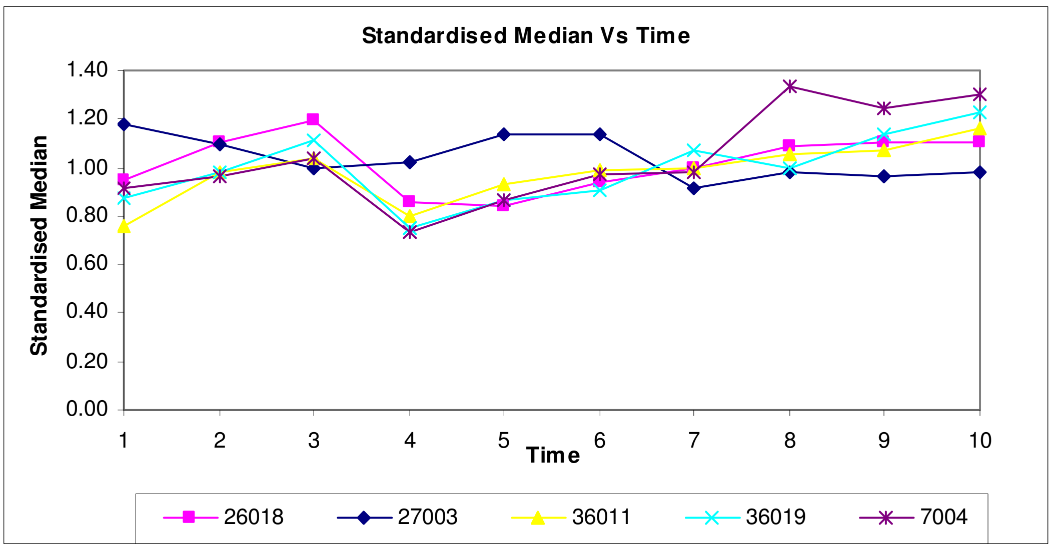
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0.20
0.00
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Time
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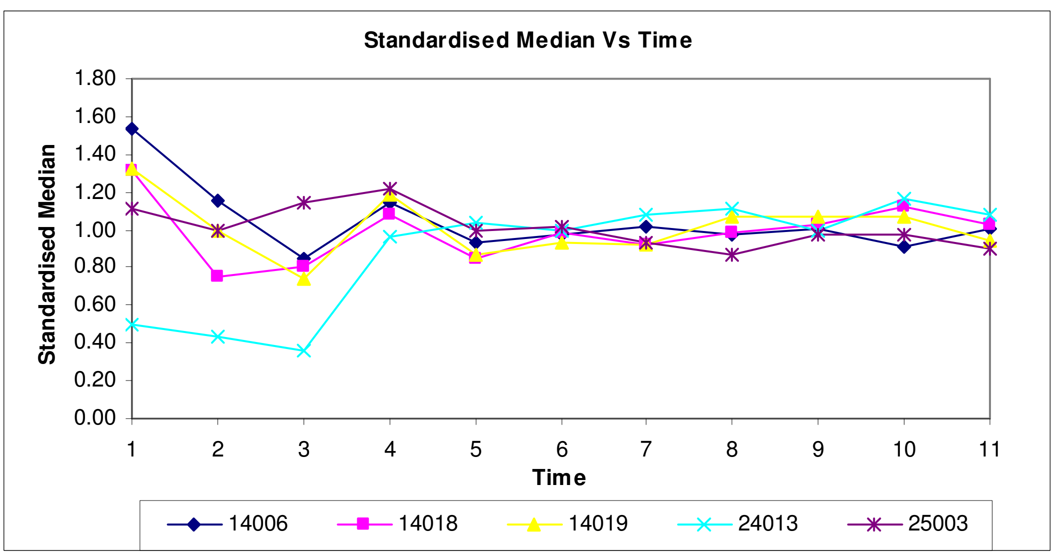
27003
36011
36019
7004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Standardised Median
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1.20
1.00
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0.20
0.00
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Time
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14018
14019
24013
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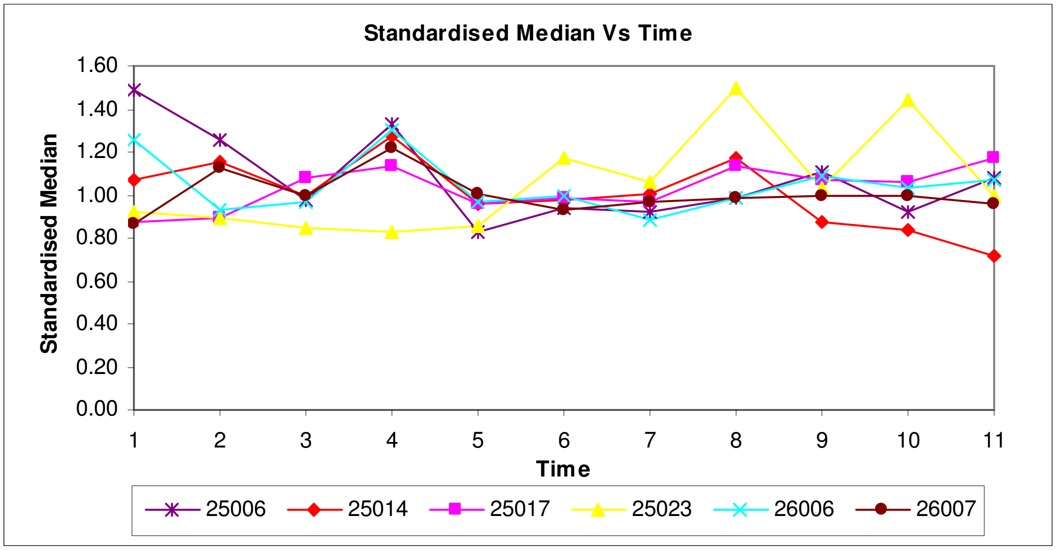
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0.20
0.40
0.60
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1.60
1 2 3 4 5 6 7 8 9 10 11
Time
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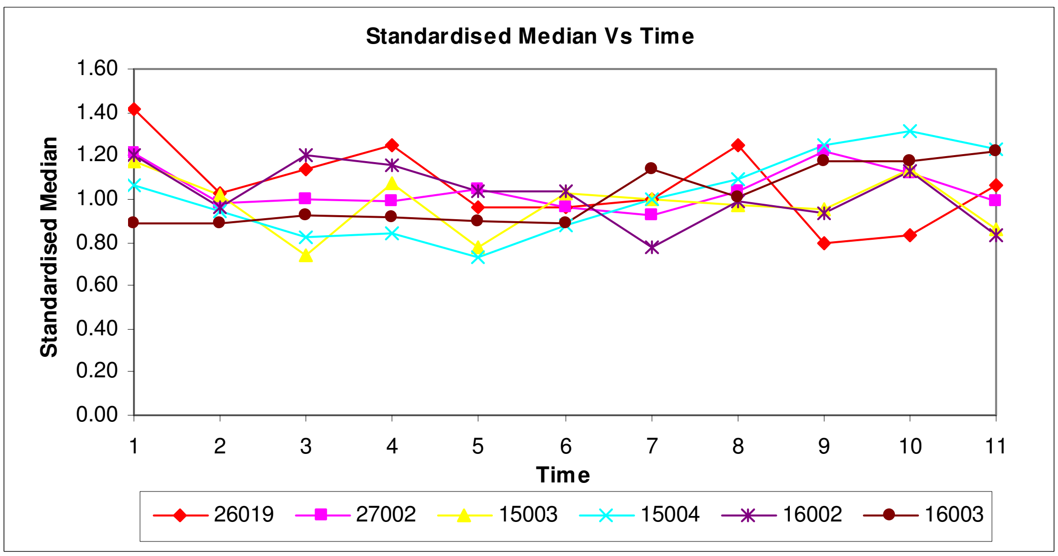
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0.40
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1 2 3 4 5 6 7 8 9 10 11
Time
26019
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15004
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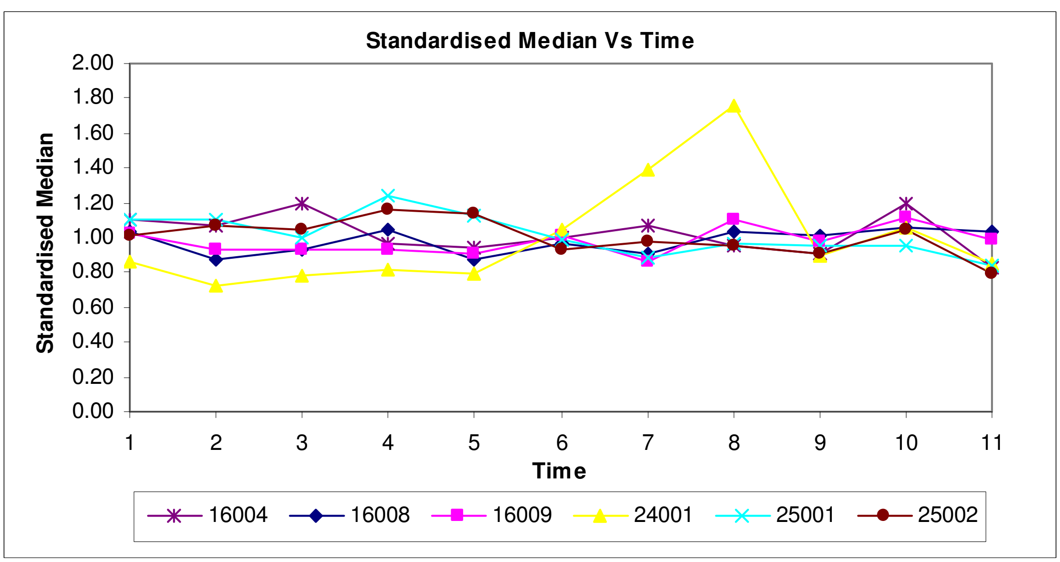
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2.00
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Time
16004
16008
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24001
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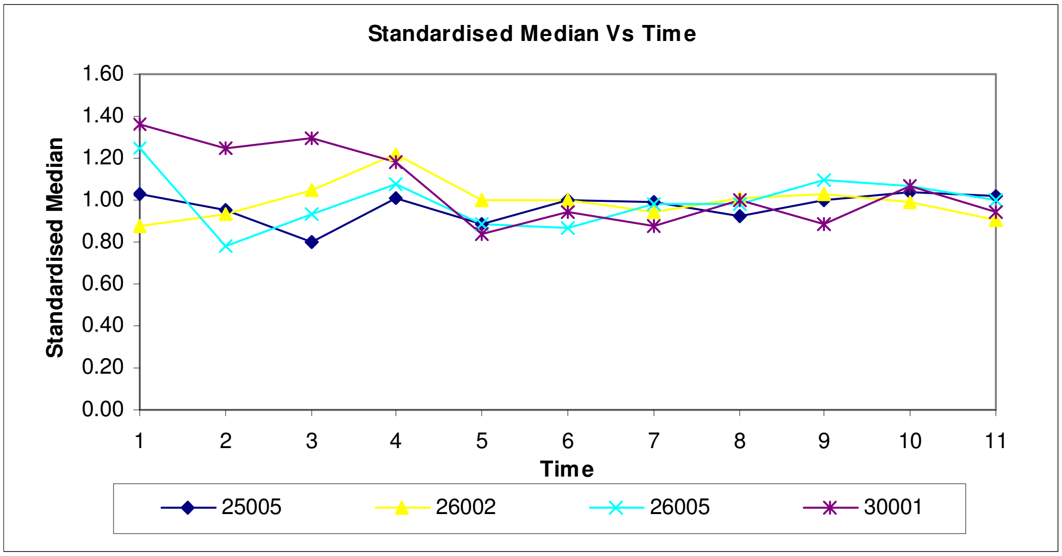
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Time
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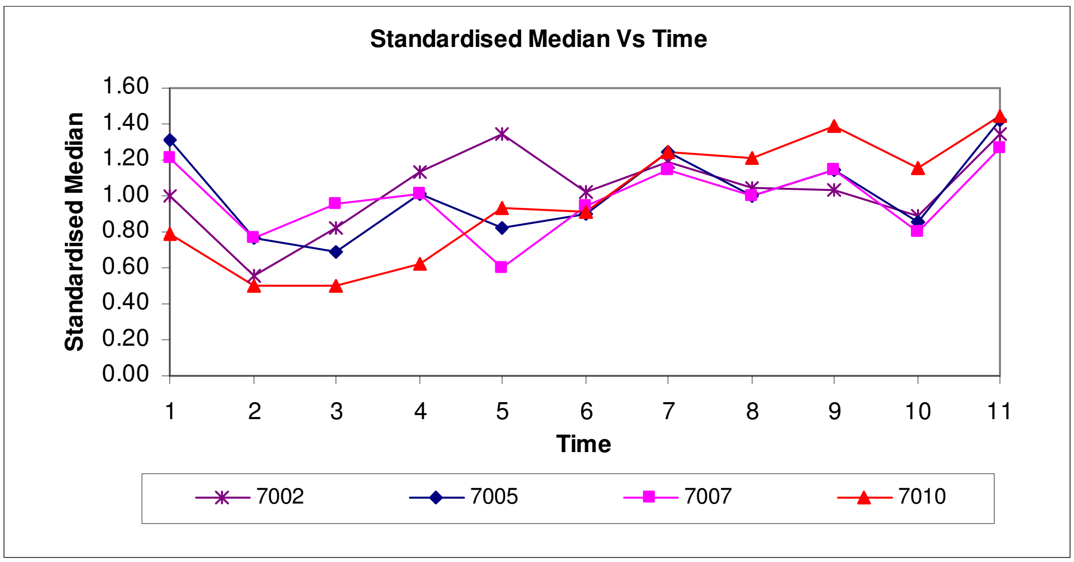
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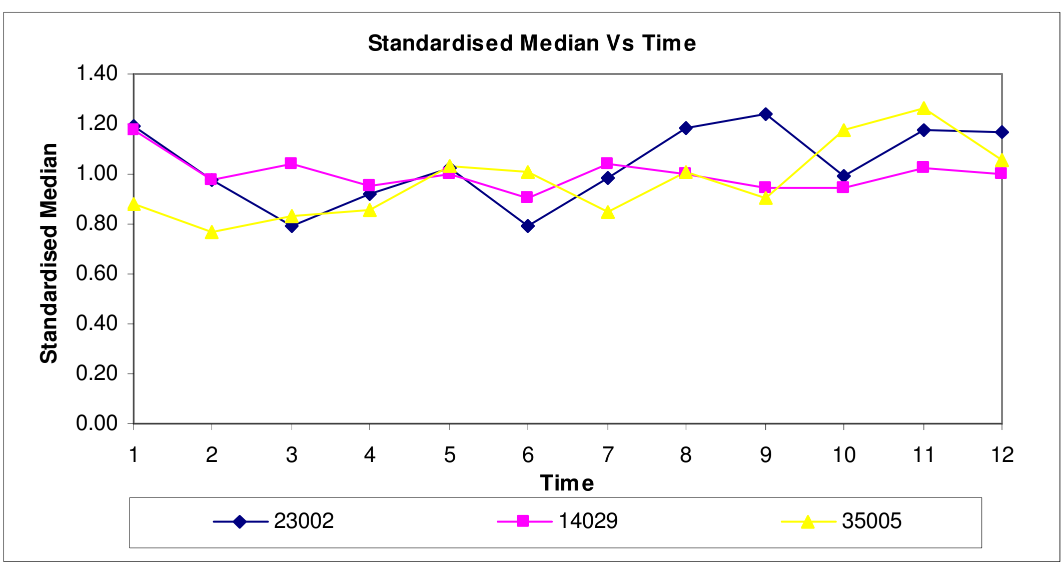
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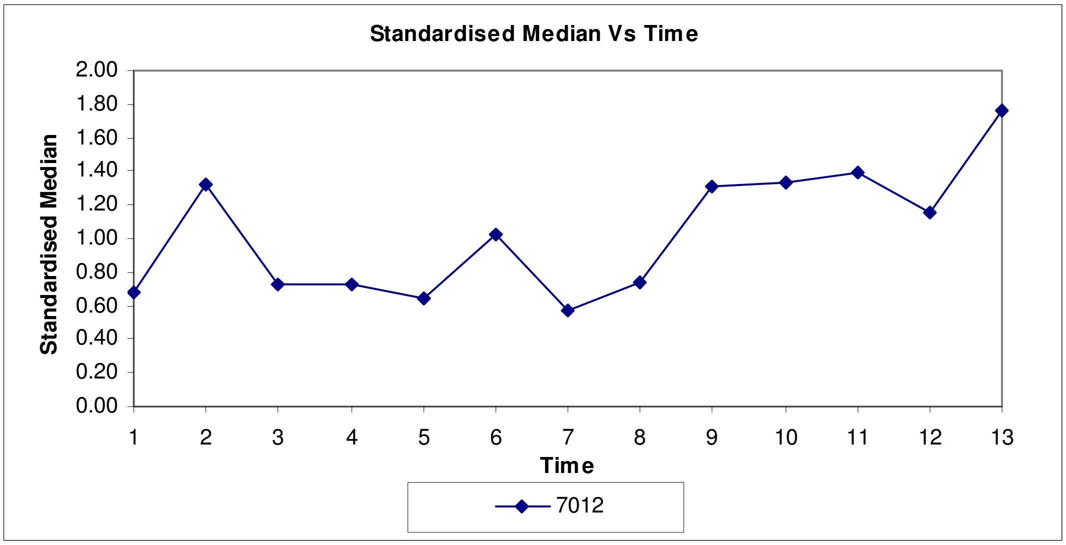
Standardised Median Vs Time
Standardised Median
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1.60
1.40
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1.00
0.80
0.60
0.40
0.20
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13
Time
7012