THE RELATIONSHIP BETWEEN TURBIDITY AND SUSPENDED SOLIDS IN FINAL EFFLUENTS

WATER QUALITY INVESTIGATIONS TEAM

OCTOBER 1993

WQI/93/21

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INTRODUCTION

The majority of STW and many other consented trade effluent discharges have, as a condition of their consents to discharge, a limit on the maximum concentration of suspended solids the effluents may contain. Samples of these effluents, and of the rivers they are discharged to are, in Wessex, routinely analysed for suspended solids. Many studies have been undertaken in the past, to look at the relationship between suspended solids concentration and turbidity in effluents. These have largely focused on the relationship for effluents in general rather than that which exists for specific discharges.

This project aimed to determine whether, for specific discharges, a predictable relationship exists. If such a relationship was found, it may be possible to use it to apply more rigorous enforcement of discharge consent conditions. Currently, routine compliance samples are taken in a non tripartite way, until a sample fails one or other of the determinand limits imposed on the consent. Subsequent samples are then taken in a tripartite manner. The weakness in this approach is that the discharge always fails to meet its consent limit on one occasion before tripartite samples are taken.

With the introduction of the Grant multimeter, which includes a built in calibrated turbidimeter, it may be possible, by considering this relationship, to determine a strong likelihood of consent failure by reference to the turbidity reading on site and initiate tripartite sampling.

This project was therefore undertaken in order to investigate the relationship between turbidity and the suspended solids concentration of effluents from selected STW's and trade effluents across Wessex. Were a regular relationship between the two parameters to be established for individual discharges, it may be possible for turbidity readings taken with the Grant hand-held multimeter at the time of routine sampling to be used to predict the likelihood of the discharge being outside its consent limit for suspended solids. A decision on whether or not tripartite sampling would be worthwhile could then be facilitated.

DATA COLLECTION

To obtain data for comparisons of the two parameters to be made, area water quality staff were asked to add the turbidity ARG (W074) to the routine effluent analysis for a list of STW's and trade effluent which they had previously nominated. Selection of works on the list was on the basis of treatment type and sampling frequency. The turbidity ARG was to be used for a period of 6 months (from January - June 1993) and works which were sampled more frequently than monthly were required in order to gather sufficient data for valid comparisons. The following works were selected for the investigation:-

Bristol Avon	Somerset	Avon and Dorset
Avonmouth STW	Bridgwater STW	Dorchester STW
Frome STW	Chard STW	Holdenhurst STW
Melksham STW	Spaxton STW	Kinson STW
Saltford STW	Shepton Mallet STW	Palmersford STW
Sherston STW	Taunton STW	Poole STW
Trowbridge STW	Wellington STW	Salisbury STW
Westbury STW	Wick St.Lawrence STW	Shaftesbury STW
Hinton Poultry (Norton St.Philip)	Yeovil STW	Tarrant Crawford STW
Buxted Poultry (Sutton Benger)	Cannington Creamery	Wareham STW
Staplemead Creamery (Frome)		Warminster STW
		Wimbourne STW
		Webbs Country Foods (Shillingstone)

During the 6 months of the investigation routine samples from some of the works breached their consent conditions and these works were subsequently transferred to the tripartite sampling programme. Unfortunately, turbidity analysis was not carried out on this programme, and as a result, insufficient turbidity data was collected for 10 of the selected works for further evaluation to be valid.

Results and Discussion

For all sites with greater than 6 samples scattergraphs have been plotted. These not only provide an immediate visual representation of trend, but also provide a baseline for later statistical interpretation. All of these scattergraphs can be found in Appendix 1.

The conventional method for plotting scattergraphs has been adopted with the independent variable (suspended solids) on the x-axis and dependent variable (turbidity) on the y-axis. To provide an immediate impression of the dispersion of the data a least squares best fit line has been added.

In order to identify any meaningful relationship between suspended solids and turbidity statistics need to be employed. At first glance it appears that all of the scattergraphs show some positive 'correlation'. There is a need, however, to determine the strength of these relationships. Correlation in statistics describes the degree of association between any two data sets. A correlation coefficient (r) is calculated and then tested against a 'table of critical values'. This test determines the probability whether, at a particular significance level, the association is due to chance variations.

There are a variety of tests of correlation. The relative merits of the different tests are bounded by the distribution of the data and size of the data set. For this reason only 21 of the original 32 sites are considered in this discussion. These sites being divided into three categories according the size of the sample population: >6-11 samples, 12- 19 samples, 20+ samples. As mentioned earlier, any sites which failed to accumulate > 6 sample results have been ignored.

Sites With >6-11 Samples

With such a limited data set it was found that the 95 % confidence limits were so wide that any correlation coefficient had little meaning. For this reason scattergraphs have been plotted but no statistical inferences have been made. It is up to the observer to draw any limited conclusions purely from visual interpretation.

Of the 8 sites in this category Wareham, Wick St Lawrence and Wellington STW's have least affinity between turbidity and solids. Staplemead Creamery together with Shepton Mallet, Taunton and Chard STW's show the greatest potential for a positive correlation. Wimbourne and Tarrant Crawford STW's appear to show a positive trend, however, the spread of points suggests that turbidity is not dependent of suspended solids alone.

Sites with 12-19 Samples

For sites with 12-19 samples a Spearman Rank correlation coefficient (r_s) has been derived. Spearman Rank is a non parametric, 'distribution-free' test; providing a useful, if not particularly robust, method of correlation for a restricted number of paired data items. The results of these tests can be found in the table below.

Site Name	Number of Samples	Correlation Coefficient	95% Confidence Limits
Warminster STW	12	r_s=0.676	0.167 - 0.901
Hinton Poultry	12	r_s=0.975	0.912 - 0.993
Poole E STW	13	r_s=0.841	0.540 - 0.951
Bridgwater STW	16	r_s=0.790	0.484 - 0.924
Hold'hurst STW	15	r_s=0.463	-0.006 - 0.788
Frome STW	18	r_s=0.885	0.717 - 0.956

Correlation coefficients are devised so that a perfect positive correlation has a coefficient of +1, and perfect negative correlation -1. A random association between two variables will have a correlation coefficient near 0.

When looking at critical value of r, all of the above correlation coefficients are found to significant at a 0.05 level, or to put it another way there are only 5 chances in 100 that each coefficient would occur from randomly paired data.

In general, the larger the positive value of r the more significant the result. More importantly, however, are the confidence limits associated with each correlation coefficient. The wider the confidence limits, the more uncertain we can be of a strong positive relationship. For example, while r_s=0.841 for Poole Eastern STW the confidence limits of this coefficient vary between 0.540-0.951. This variation is echoed by the scattergraph. Conversely, the high correlation coefficient produced by Hinton Poultry is bounded by a very narrow range of confidence limits. For this reason it seems logical to suggest that a more direct relationship exists.

It should be remembered that the correlation coefficient only *describes* the degree of association, and that no *causal* link can be deduced from this alone; Cause and effect can only be decided through other evidence and judgement of the observer (Hammond and McCullugh 1982). While the correlation coefficients do describe a general trend of positive association between turbidity and suspended solids, others factors need to be considered on a site by site basis to determine whether the relationship is valid.

The spread of data on the scattergraphs of Bridgwater, Holdenhurst, Frome and Poole Eastern suggest that although there is good correlation, suspended solids may not be the dominant factor influencing turbidity. However, Hinton Poultry and Warminster STW (excluding 1 outlier) show a strong straight line relationship and maybe worth further investigation.

Sites with 20+ Samples

For the sites in this category, having a greater number of samples, a more powerful parametric test of correlation can be used. Parametric tests rely on the background population from which the samples are drawn being *normally* distributed. From examination of the data, in this survey, it has been found that the distribution of the sample populations of both suspended solids and turbidity are *log normal*.

The Pearson Product Moment Correlation Coefficient (r) parametric test has been adopted; as a parametric test, it assumes that the data is normally distributed. By taking logs of the suspended solids and turbidity data their distributions were transformed to a near normal distribution before the coefficient was derived. The results of these tests can be found in the table below. The test has been performed at a 0.05 significance level.

Site Name	Number of Samples	Correlation Coefficient	95% Confidence Limits
Kinson STW	21	r=0.771	0.509 - 0.902
Palmersford STW	22	r=0.872	0.713 - 0.946
Avonmouth STW	24	r=0.708	0.426 - 0.864
Salisbury STW(2)	25	r=0.819	0.642 - 0.913
Trowbridge STW	26	r=0.878	0.745 - 0.945
Salisbury STW(1)	28	r=0.802	0.612 - 0.904
Saltford STW	26	r=0.711	0.477-0.861

The scattergraph for each of the sites in this category suggest a strong positive correlation between turbidity and suspended solids and this is manifested in the Pearson Product Correlation Coefficients above. All are found to be significant at the 0.05 level. As previously mentioned, a perfect positive correlation has a coefficient of +1.

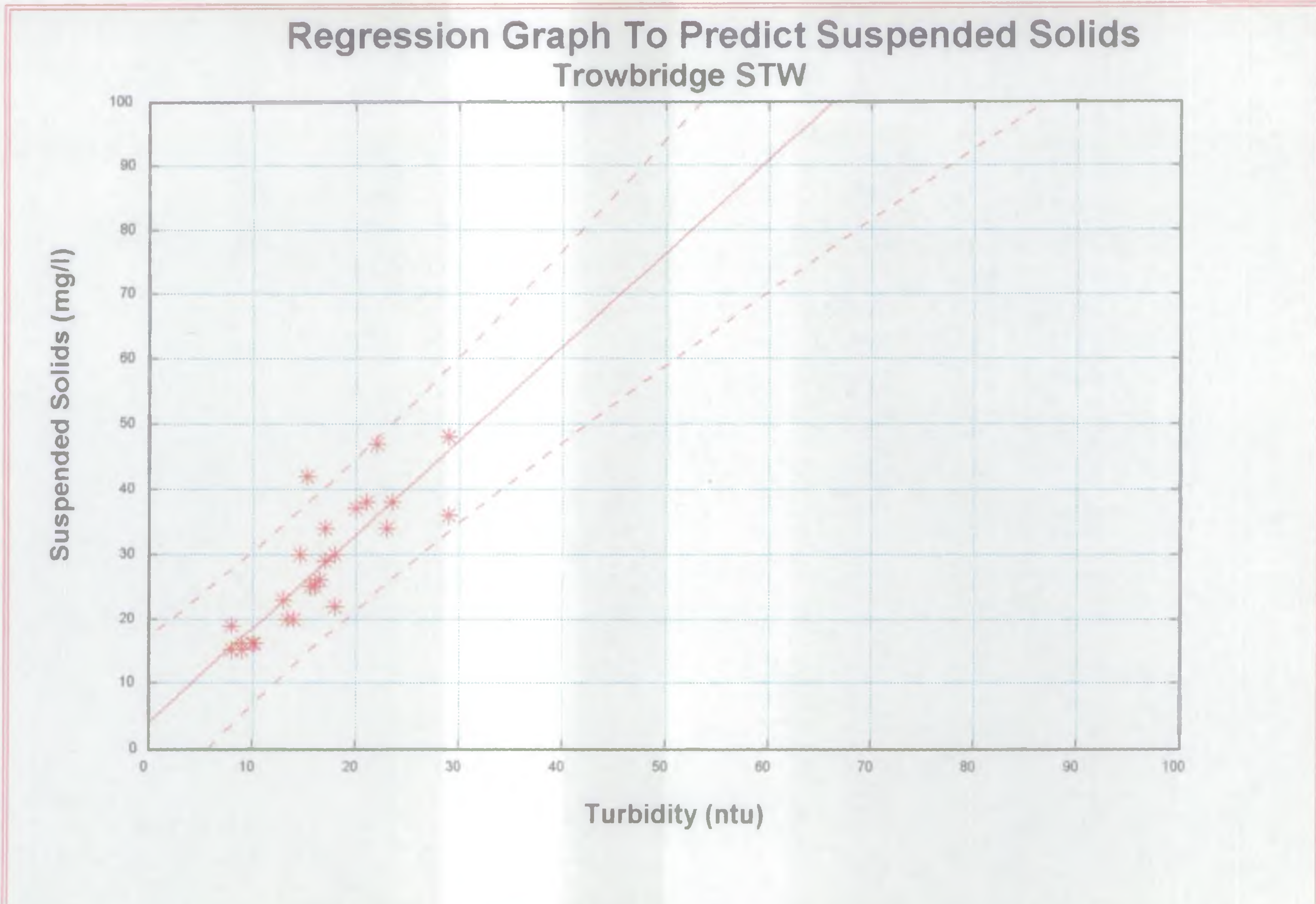
The correlation coefficient and significance tests have shown that there is a strong degree of association between turbidity and suspended solids at these STWs, however, they provide no indication of how they are related. This relationship needs to be explained more fully if any estimates of suspended solids are to be made from a knowledge of turbidity: such statistical explanation requires regression analysis.

Regression, of a sort, has already been performed to some extent as a regression line is simply a line of best fit on a scattergraph. If a perfect correlation (r=1) existed between suspended solids and turbidity the points on each scattergraph would lie on a straight line. This is obviously not the case, however, it is possible to make inferences about the relationship from the spread of residuals (deviations from the best fit line) on each scattergraph: this type of statistical inference is called prediction.

In order for values of suspended solids to be 'predicted' from given values of turbidity the scattergraphs need to be redrawn with turbidity as the independent factor and so plotted on the x-axis. The scattergraph for Trowbridge STW has been replotted to demonstrate how a predictive model could be derived.

The higher the correlation between two variables (the predictor and predicted), the more accurately and confidently predictions can be made. As turbidity and suspended solids are not correlated perfectly it is impossible to predict with <u>complete</u> accuracy and reliability. It is possible, however, to estimate with a given level of confidence the range within which the value will lie. On the scattergraph the dashed lines either side of the regression line signify the 95% confidence limits of the actual value of suspended solids for any given value of turbidity. It could be assumed, therefore, that for any turbidity value falling between the dashed lines, the corresponding suspended solids result maybe estimated at a 95% confidence level.

It should be noted that predicting suspended solids values by extrapolation is dangerous because there maybe important thresholds determining the


Regression Graph To Predict Suspended Solids
Trowbridge STW
Suspended Solids (mg/l)
Turbidity (ntu)
0
10
20
30
40
50
60
70
80
90
100

relationship beyond the spread of available data. With data sets limited to 20-30 samples there is a strong possibility that the full potential range of the relationship is missed.

Conclusions

Previous to this report it has been widely accepted that whilst turbidity is influenced by suspended solids, it is also affected by a number of other variables (colour, the physical properties of the solids etc) and that there is no direct relationship between the two. This investigation, however, has shown fairly convincingly that turbidity and suspended solids have a close association. A strong positive correlation has been demonstrated by the use of scattergraphs and confirmed by Spearman Rank and Pearson Product Moment Correlation.

The main limitation put on this investigation has been the number of data items available to determine relationships. It does appear, however, that although a positive correlation exists between suspended solids and turbidity the association is stronger, for whatever unique reasons, at particular sites.

Recommendations

1. For sites which show the strongest correlation (Hinton Poultry, Palmersford, Trowbridge, Kinson) it maybe worth continuing to collect turbidity data for at least another 6 months, and even longer for those sites sampled less frequently than weekly. Collecting supplementary turbidity data on a routine basis should not prove too onerous as it only requires the addition of the turbidity ARG to existing MENSAR runs. No extra sampling effort is needed.

2. A greater number of data items (80-100 samples) will produce a better idea of the total possible dispersion of the data at any site; reflecting a better range of conditions under which each individual discharge operates. On this site by site basis, if the correlation between suspended solids and turbidity continues to be good, regression may be employed to produce a graph which predicts suspended solids consent failure in the field from multimeter turbidity readings.

3. The Grant hand-held multimeter uses a different method of determining turbidity than the bench method used by Exeter laboratory. For this reason it is recommended that a separate project should be undertaken to compare multimeter readings with turbidity results produced by the lab. It is anticipated, however, that significant differences would not be found.

4. A similar exercise to this study to establish whether an association between *BOD* and turbidity exists may be useful. If such a relationship is found in situ turbidity readings will become even more useful in determining consent failure in the field.

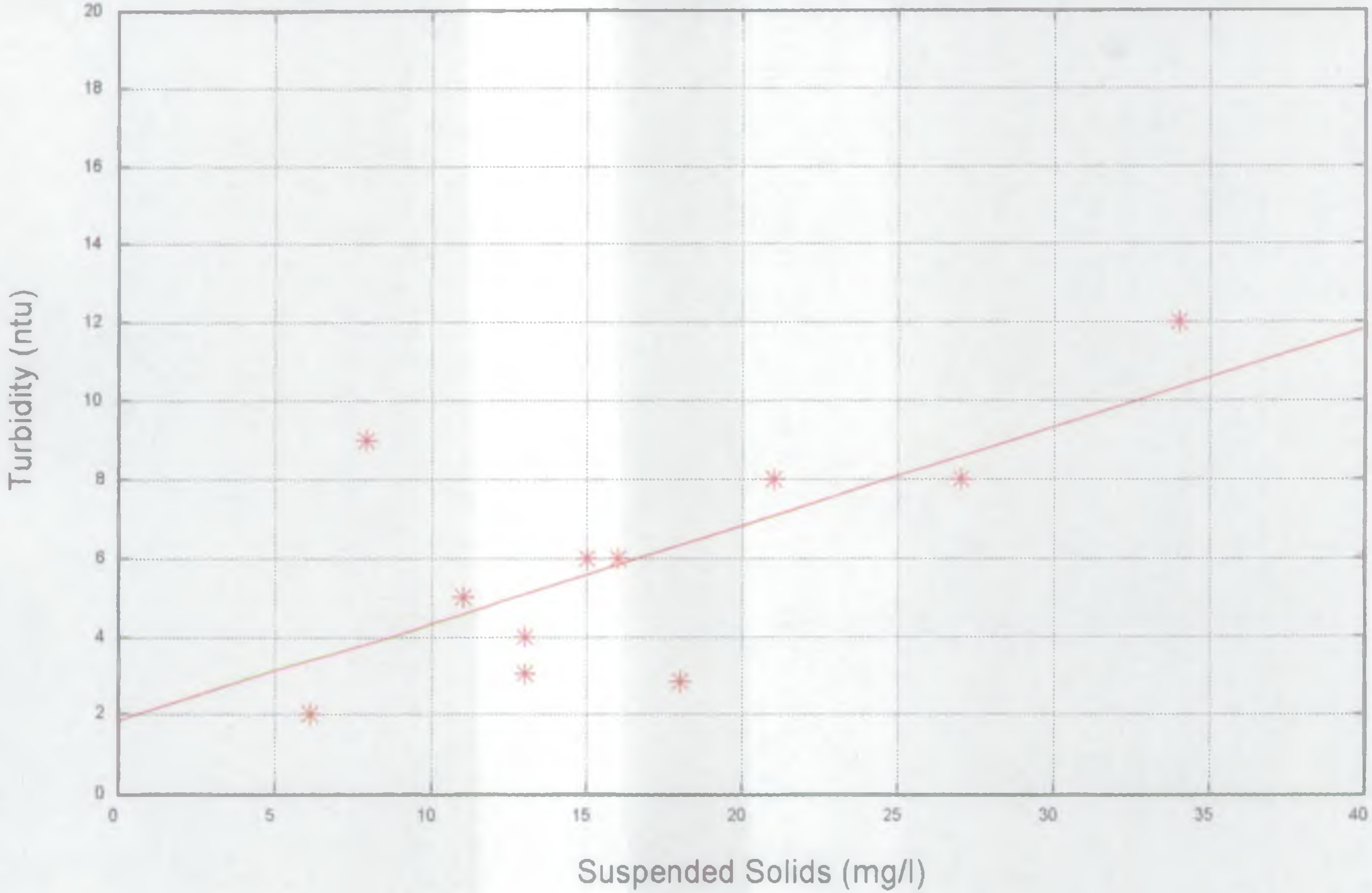
References

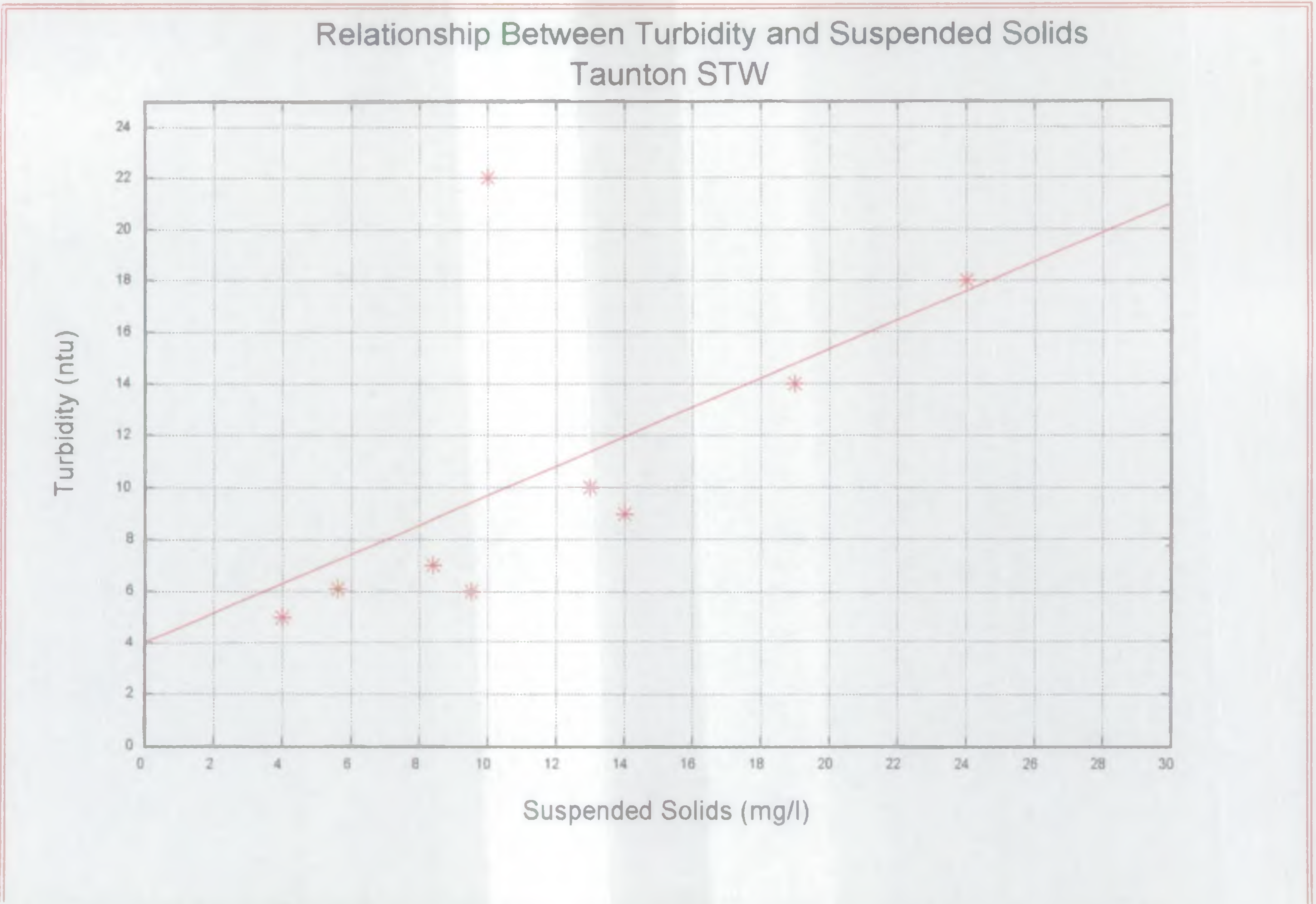
Hammond R and McCullagh P S 1982 *Quantitative Techniques In Geography: An Introduction.* Clarendon Press

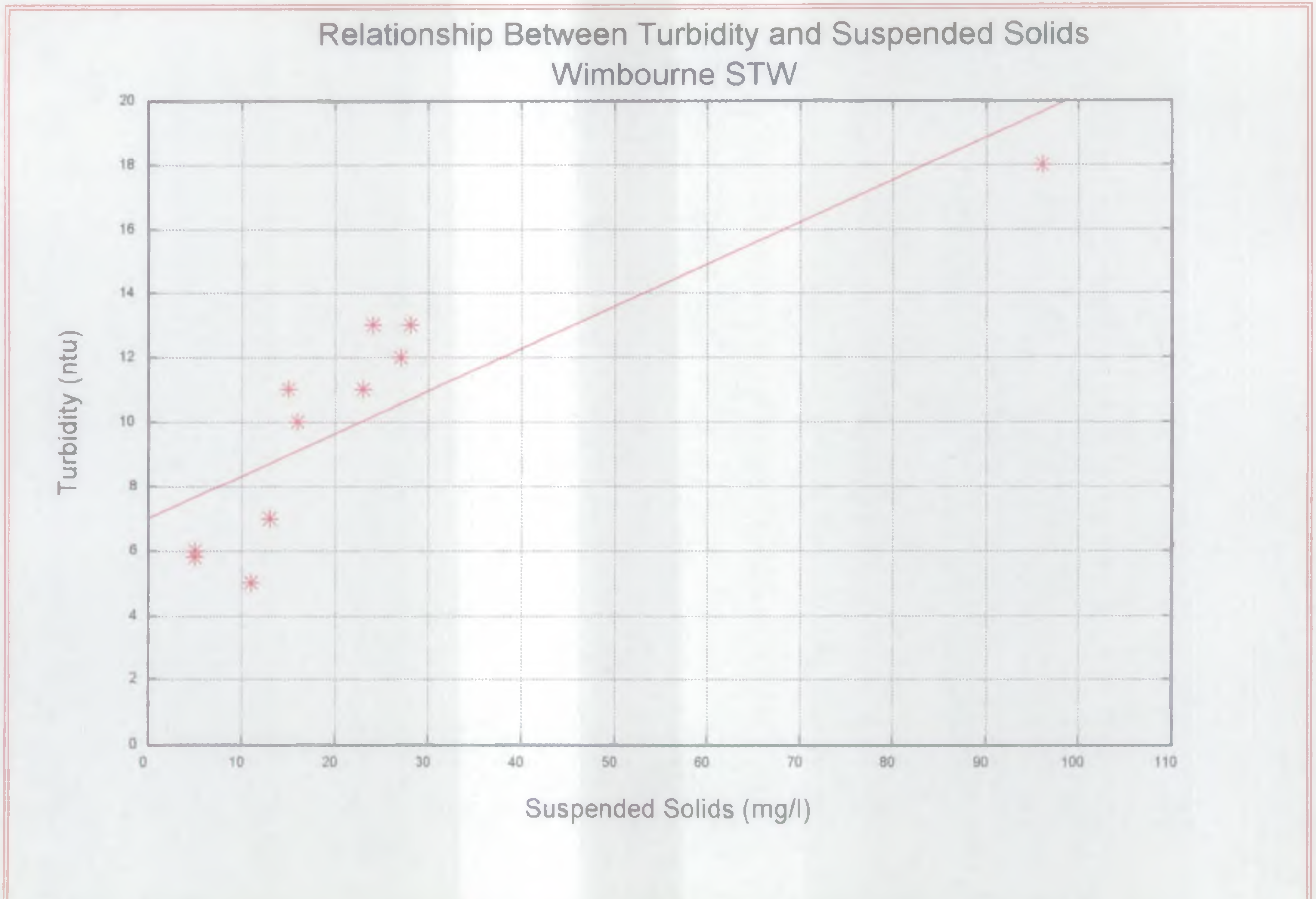
Hayton R D and Long T M 1989 *Evaluation Of Turbidity Instruments At A Water Treatment Works: Summary.* WRc Report No. FR 0044

APPENDIX 1

Relationship Between Turbidity and Suspended Solids
Staplemead Creamery

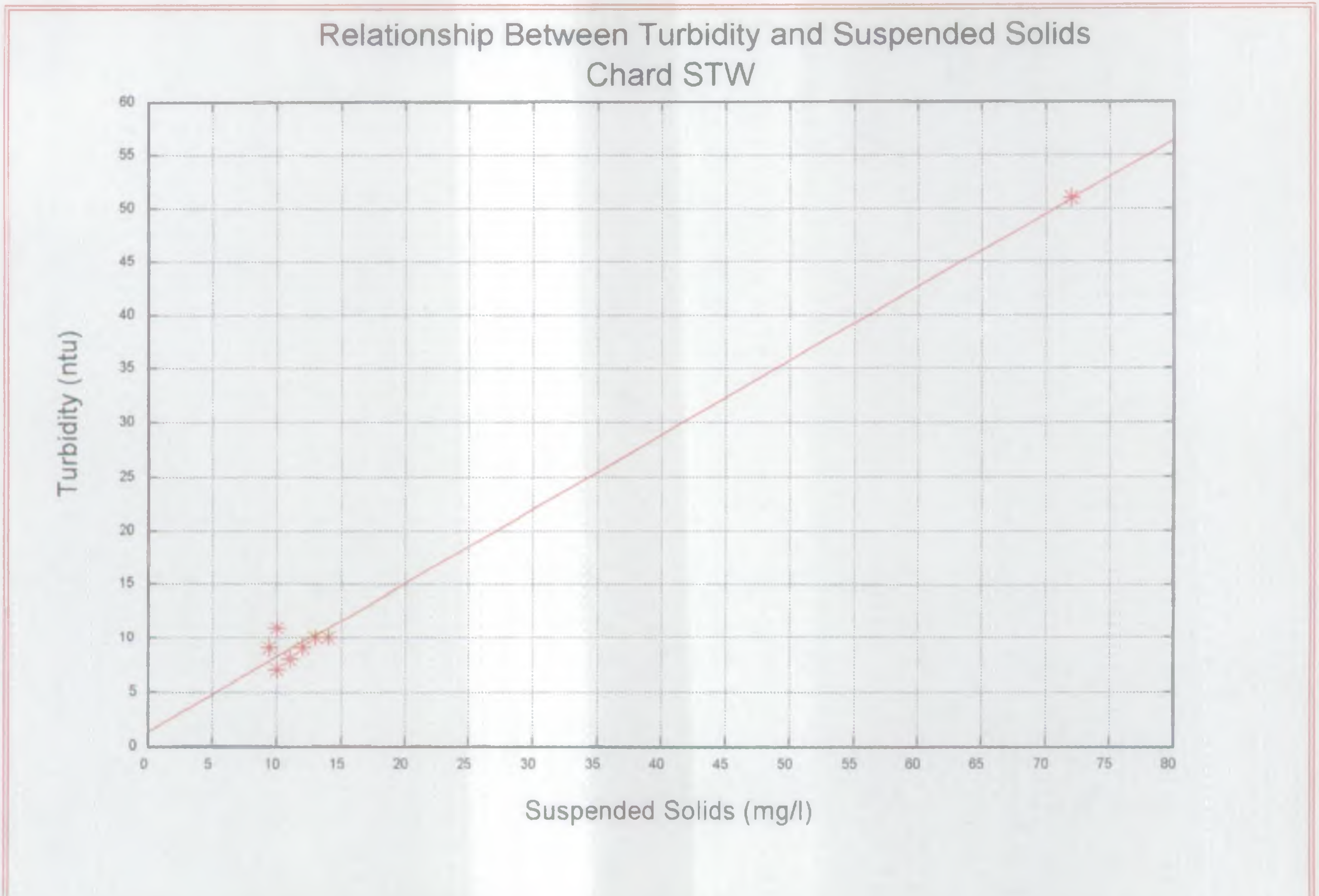



Relationship Between Turbidity and Suspended Solids
Taunton STW
Turbidity (ntu)
0
2
4
6
8
10
12
14
16
18
20
22
24
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
Suspended Solids (mg/l)

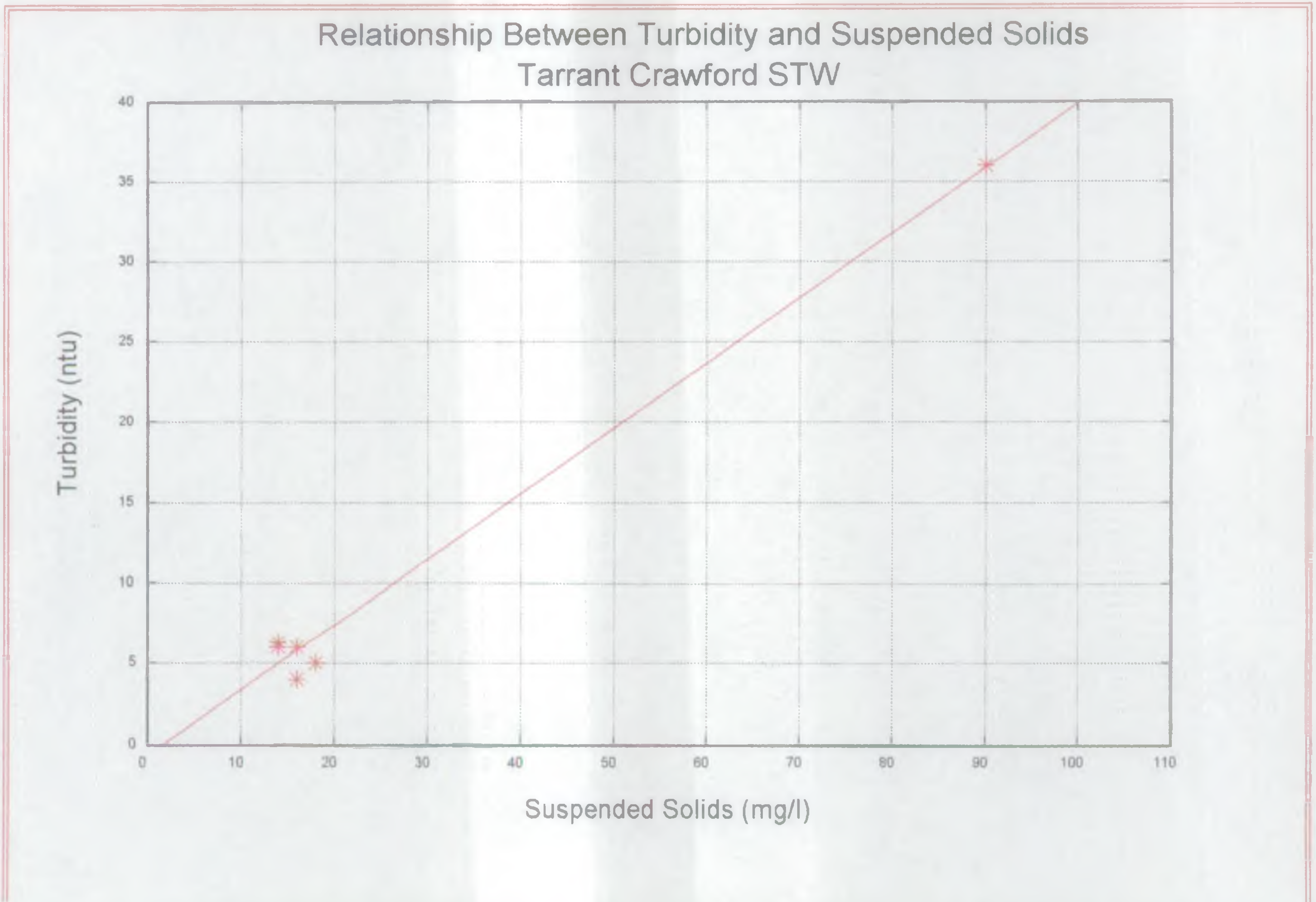


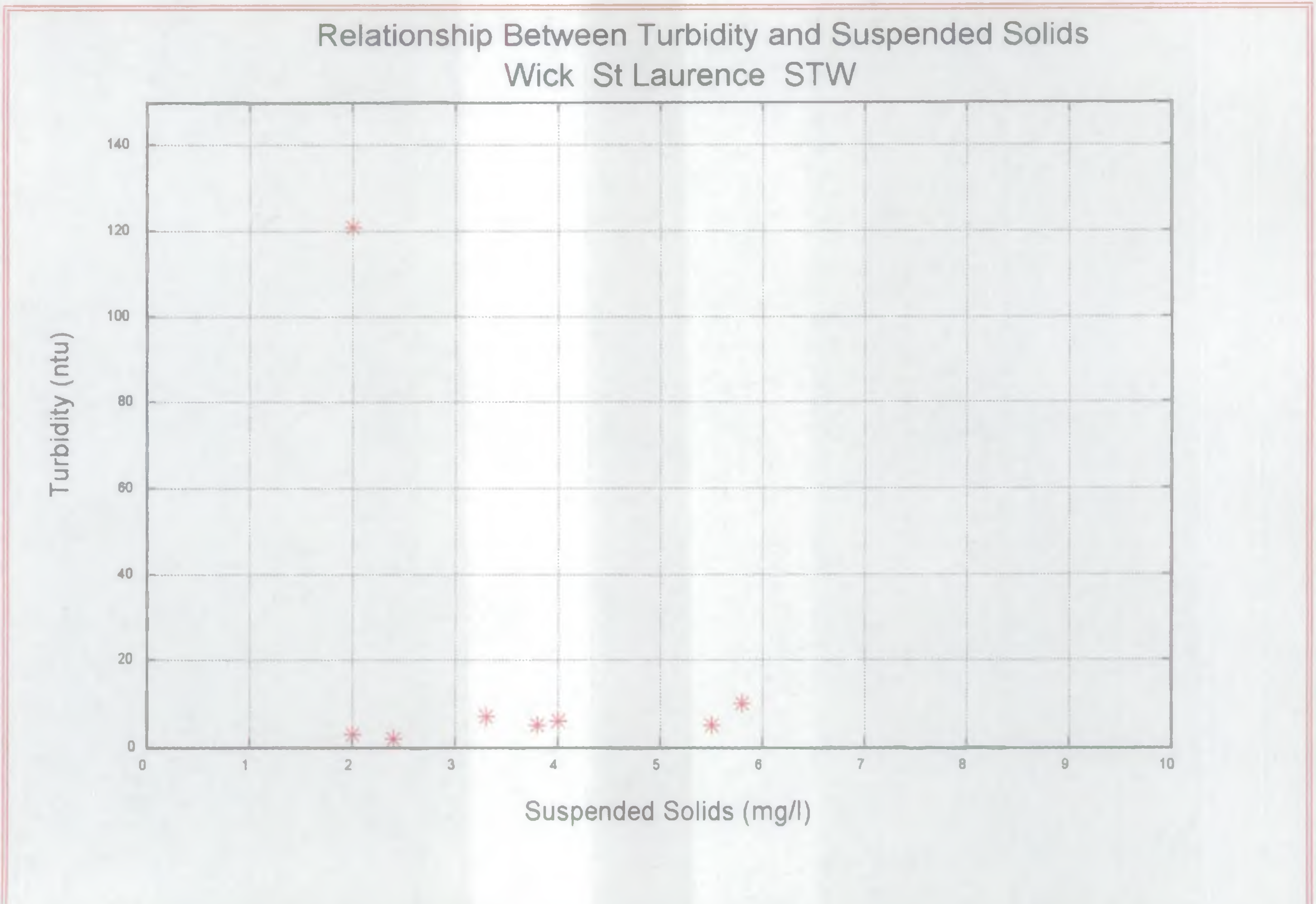
Relationship Between Turbidity and Suspended Solids
Wimbourne STW
Turbidity (ntu)
Suspended Solids (mg/l)
0
2
4
6
8
10
12
14
16
18
20
0
10
20
30
40
50
60
70
80
90
100
110

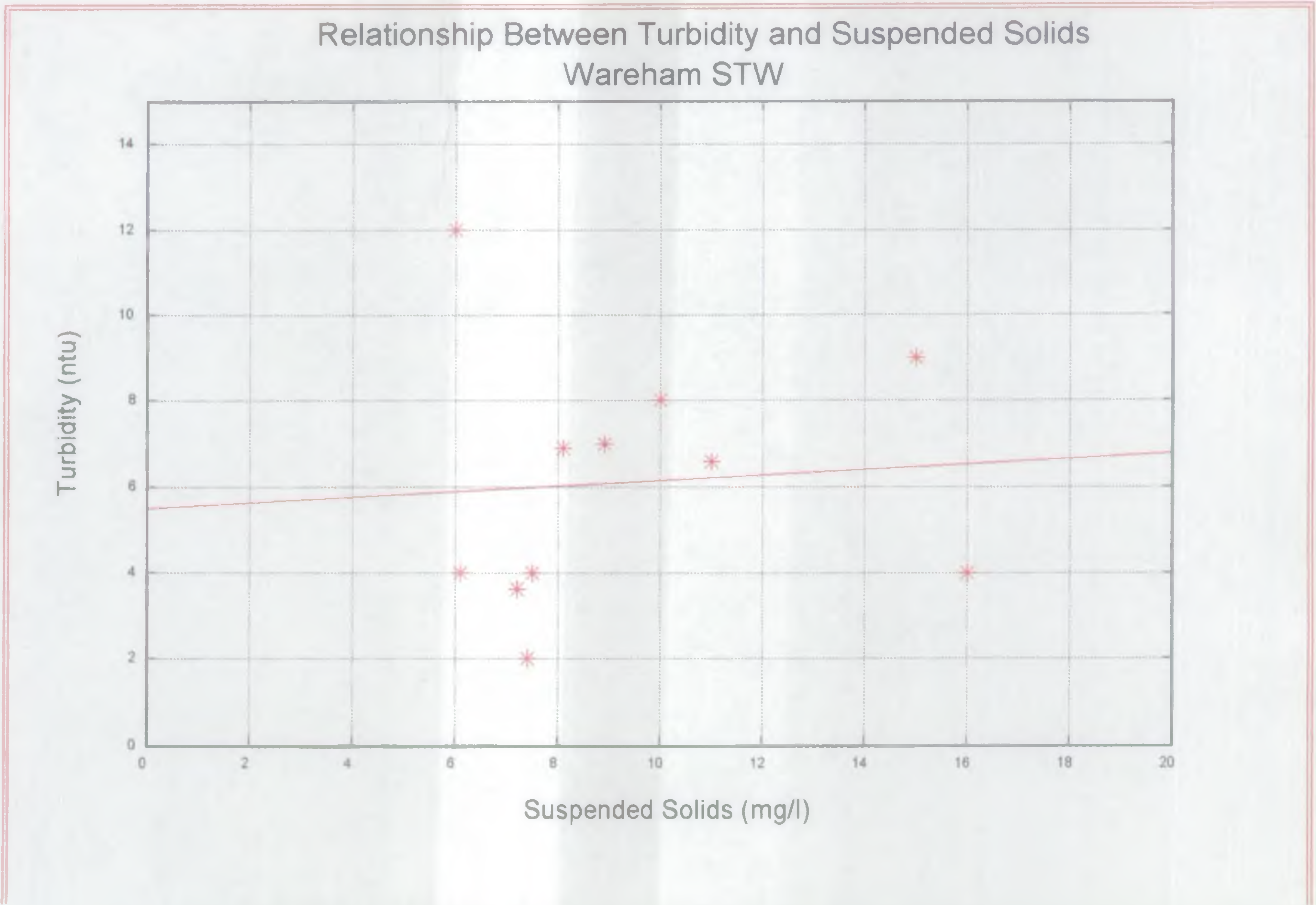

Relationship Between Turbidity and Suspended Solids
Shepton Mallet STW
Turbidity (ntu)
0
2
4
6
8
10
12
14
16
18
20
0
5
10
15
20
25
30
35
40
Suspended Solids (mg/l)



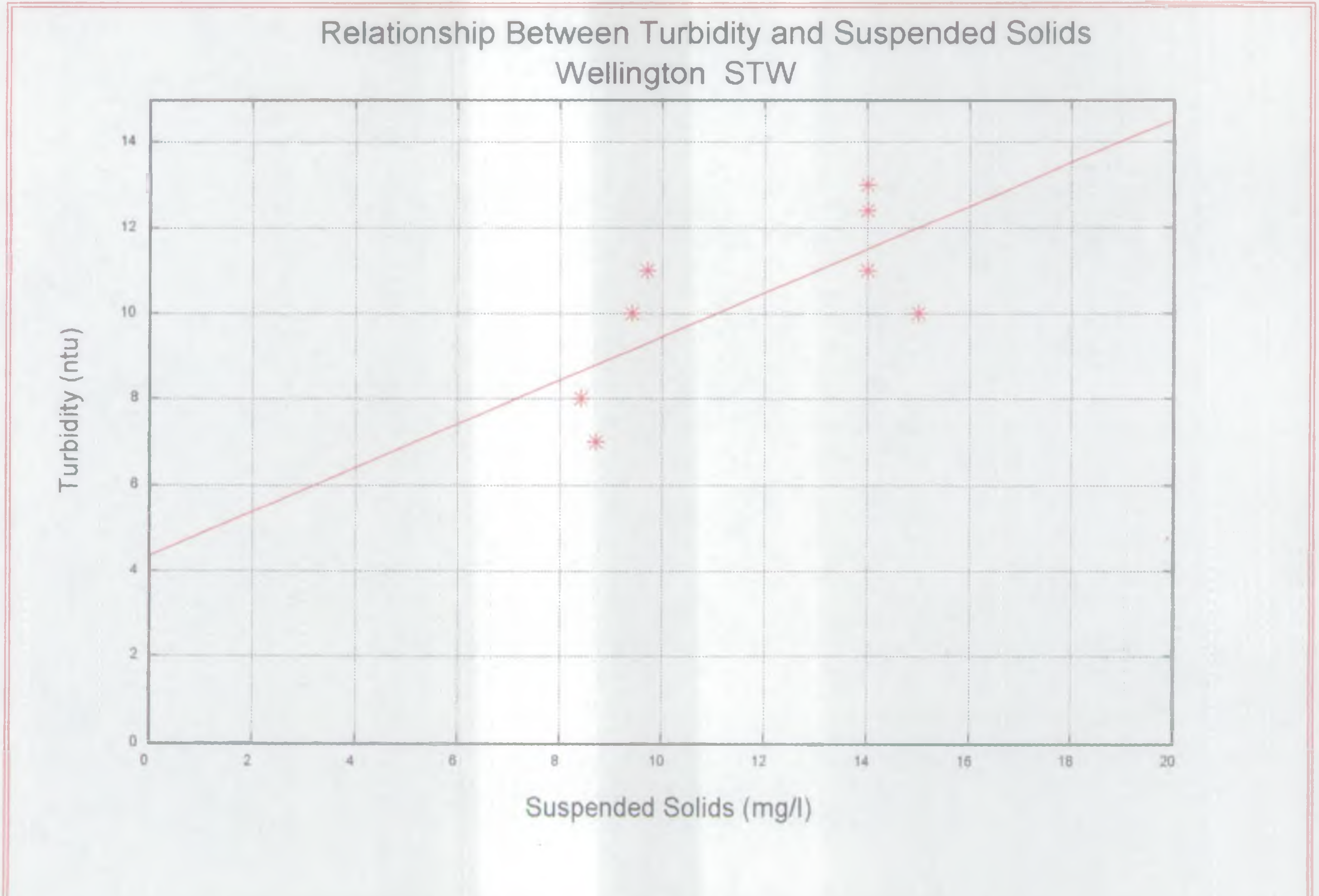
Relationship Between Turbidity and Suspended Solids
Chard STW
Turbidity (ntu)
Suspended Solids (mg/l)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80

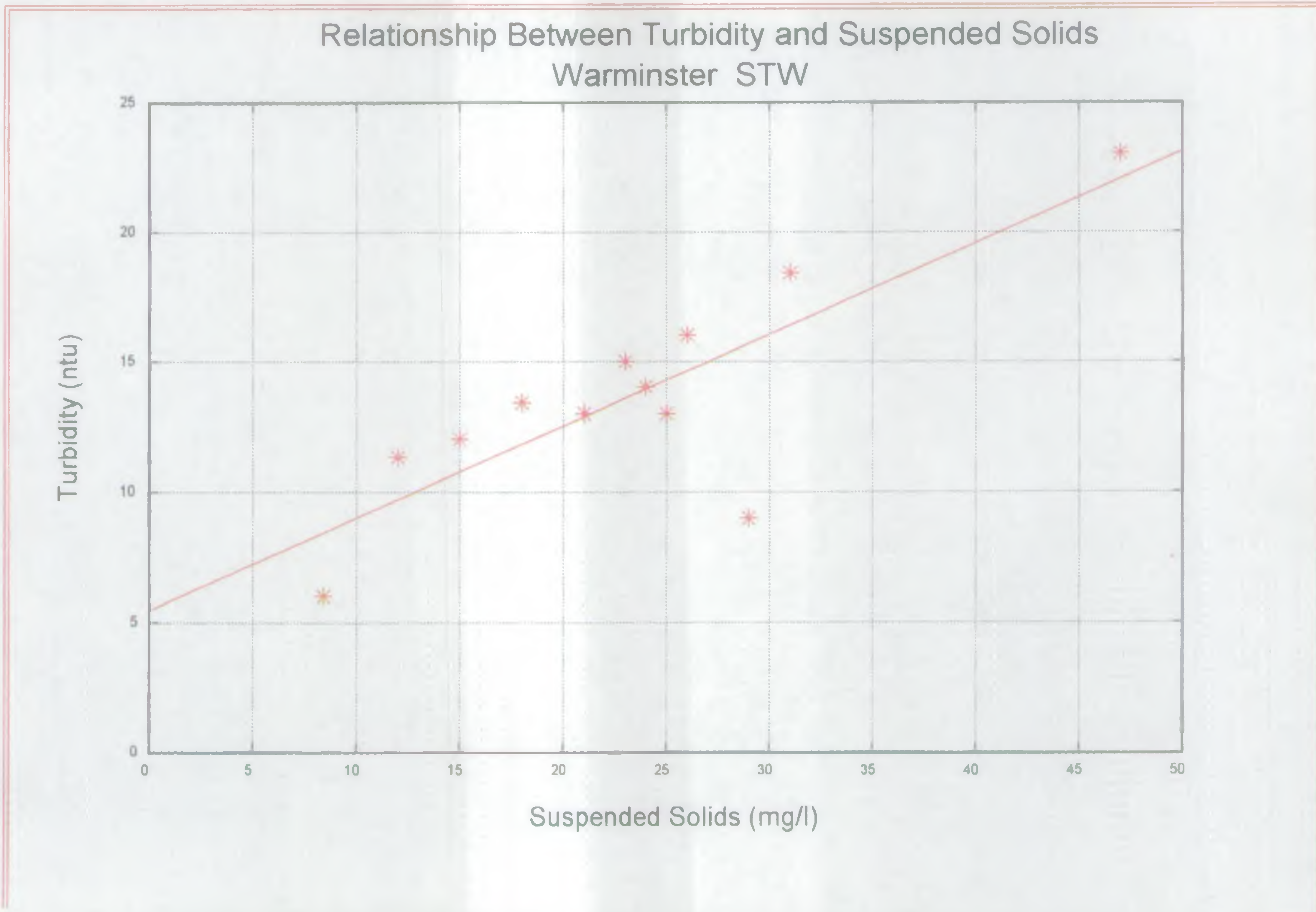

Relationship Between Turbidity and Suspended Solids
Tarrant Crawford STW
Turbidity (ntu)
Suspended Solids (mg/l)
0
5
10
15
20
25
30
35
40
0
10
20
30
40
50
60
70
80
90
100
110


Relationship Between Turbidity and Suspended Solids
Wick St Laurence STW
Turbidity (ntu)
0
20
40
60
80
100
120
140
0
1
2
3
4
5
6
7
8
9
10
Suspended Solids (mg/l)

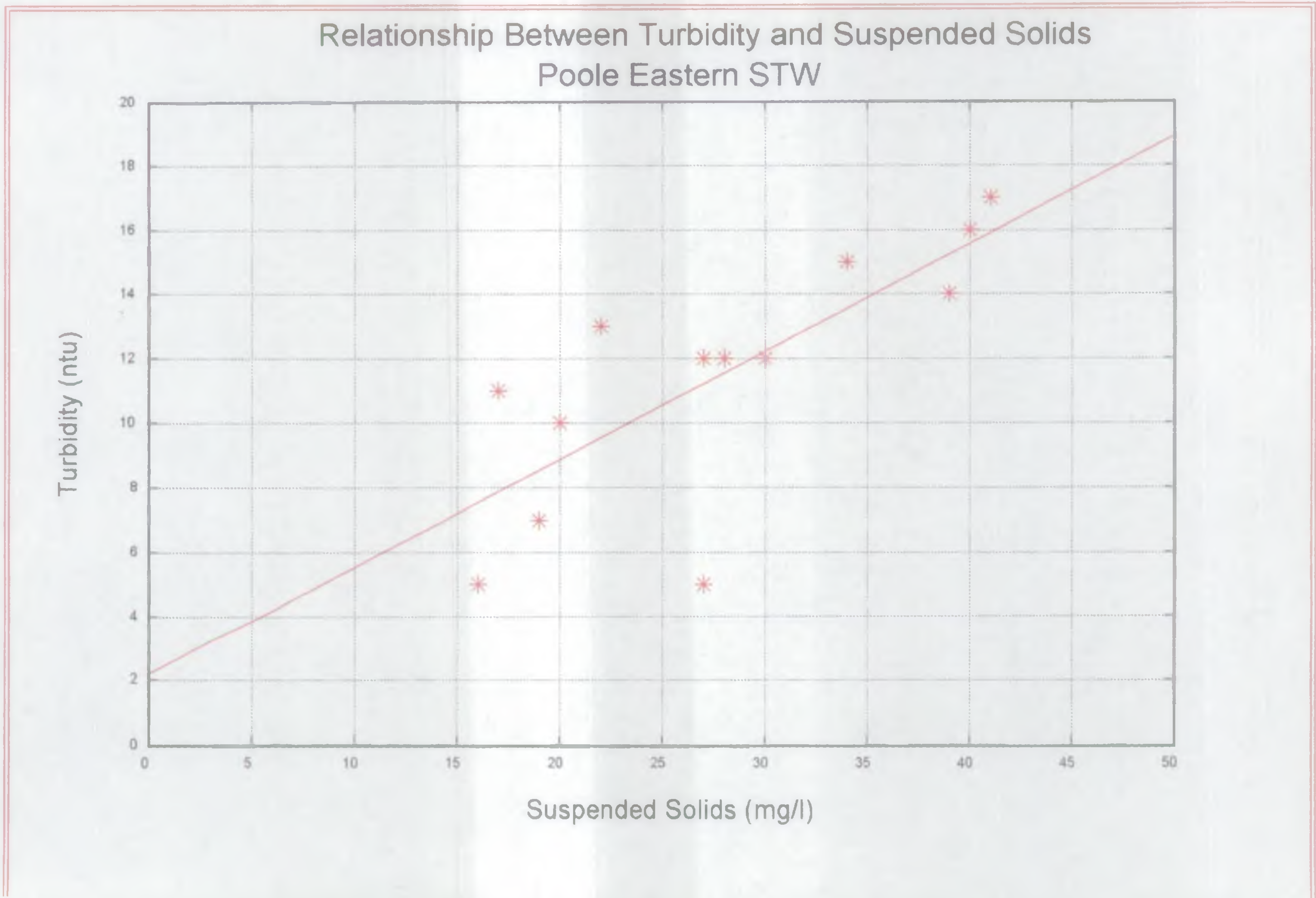


Relationship Between Turbidity and Suspended Solids
Wareham STW
Turbidity (ntu)
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
16
18
20
Suspended Solids (mg/l)

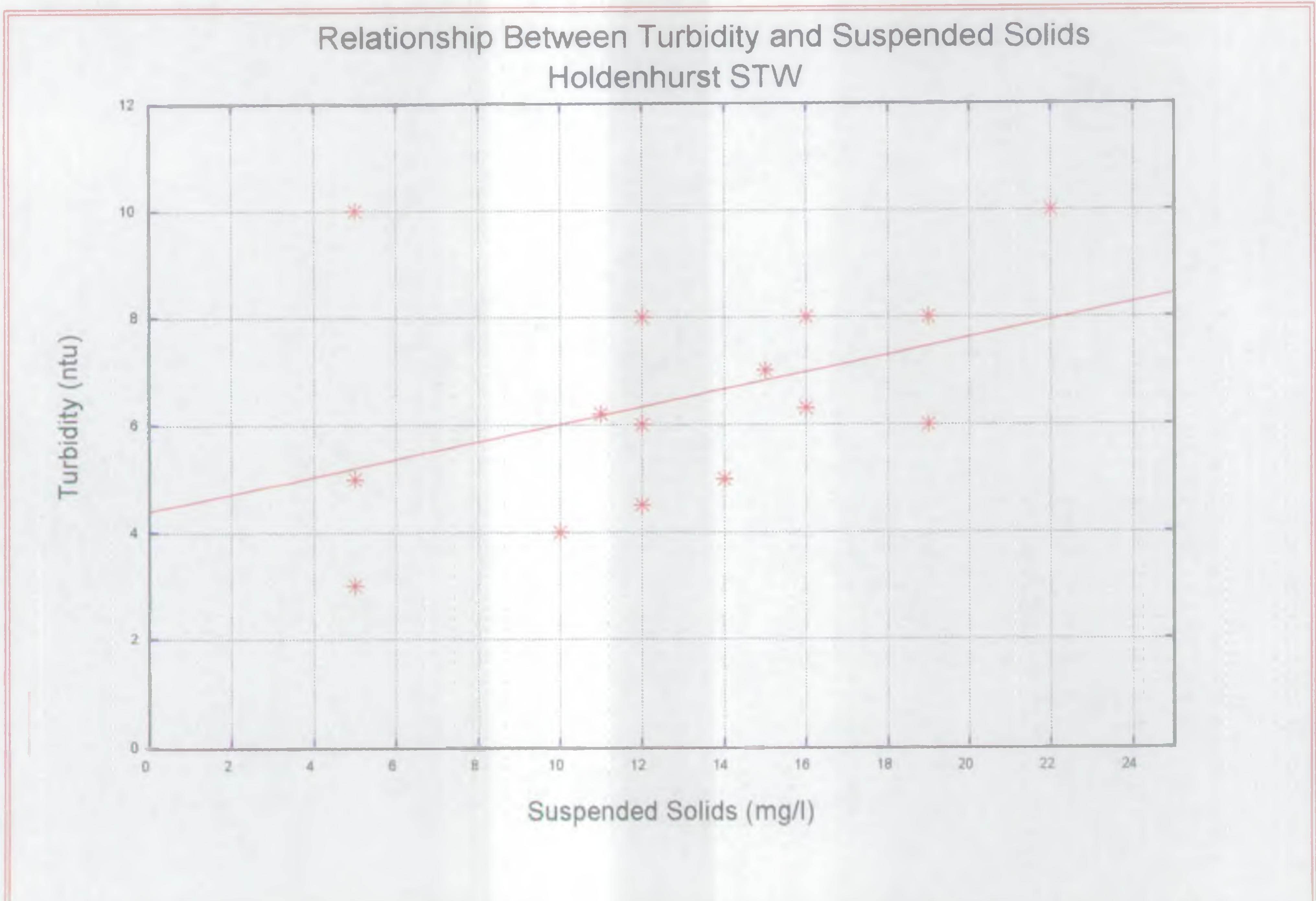

Relationship Between Turbidity and Suspended Solids
Wellington STW
Turbidity (ntu)
0
2
4
6
8
10
12
14
0
2
4
6
8
10
12
14
16
18
20
Suspended Solids (mg/l)

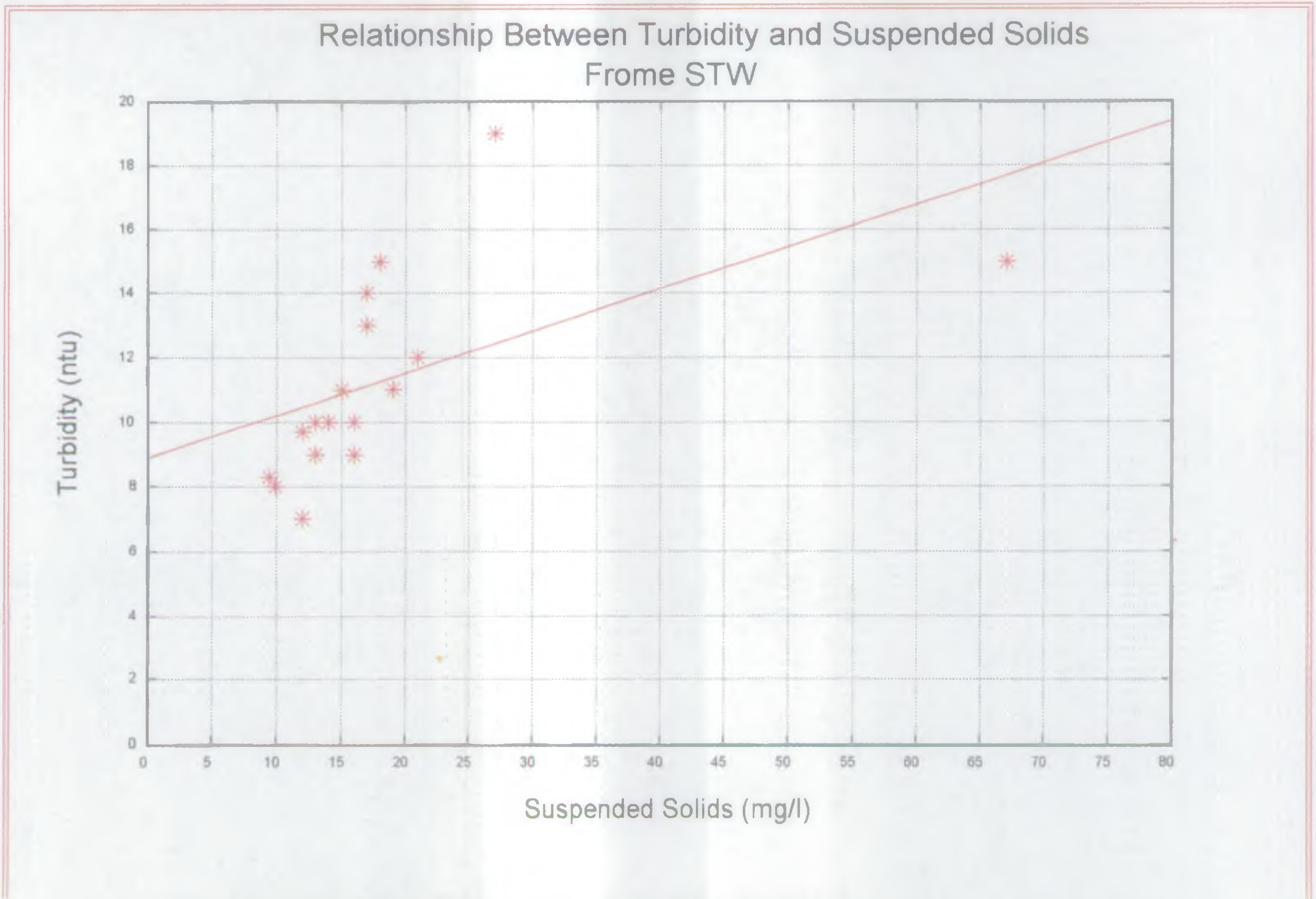

Relationship Between Turbidity and Suspended Solids
Warminster STW
Turbidity (ntu)
0
5
10
15
20
25
0
5
10
15
20
25
30
35
40
45
50
Suspended Solids (mg/l)


Relationship Between Turbidity and Suspended Solids
Hinton Poultry
Turbidity (ntu)
Suspended Solids (mg/l)
0
5
10
15
20
25
30
0
10
20
30
40
50
60
70
80

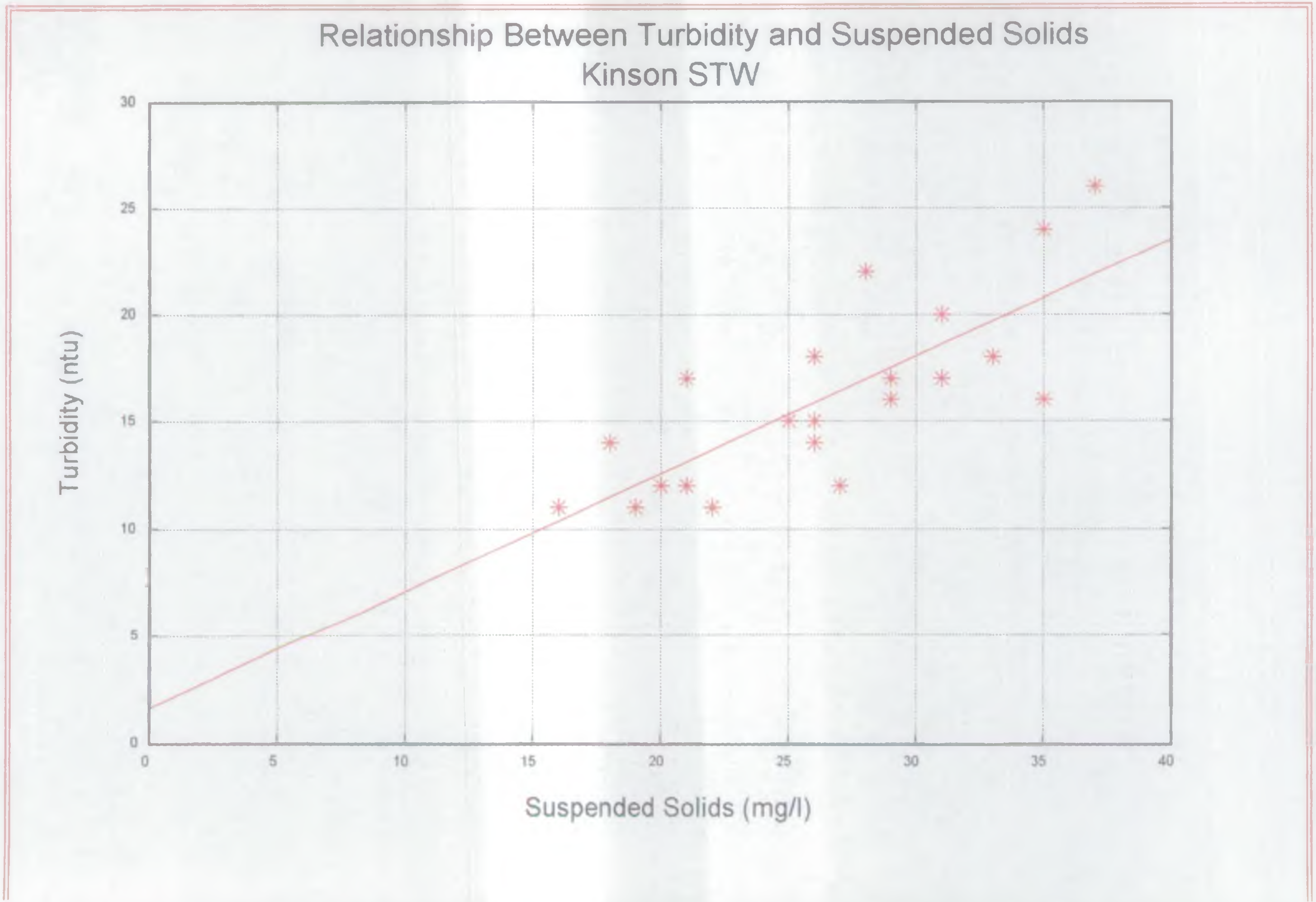

Relationship Between Turbidity and Suspended Solids
Poole Eastern STW
Turbidity (ntu)
Suspended Solids (mg/l)
0
2
4
6
8
10
12
14
16
18
20
0
5
10
15
20
25
30
35
40
45
50

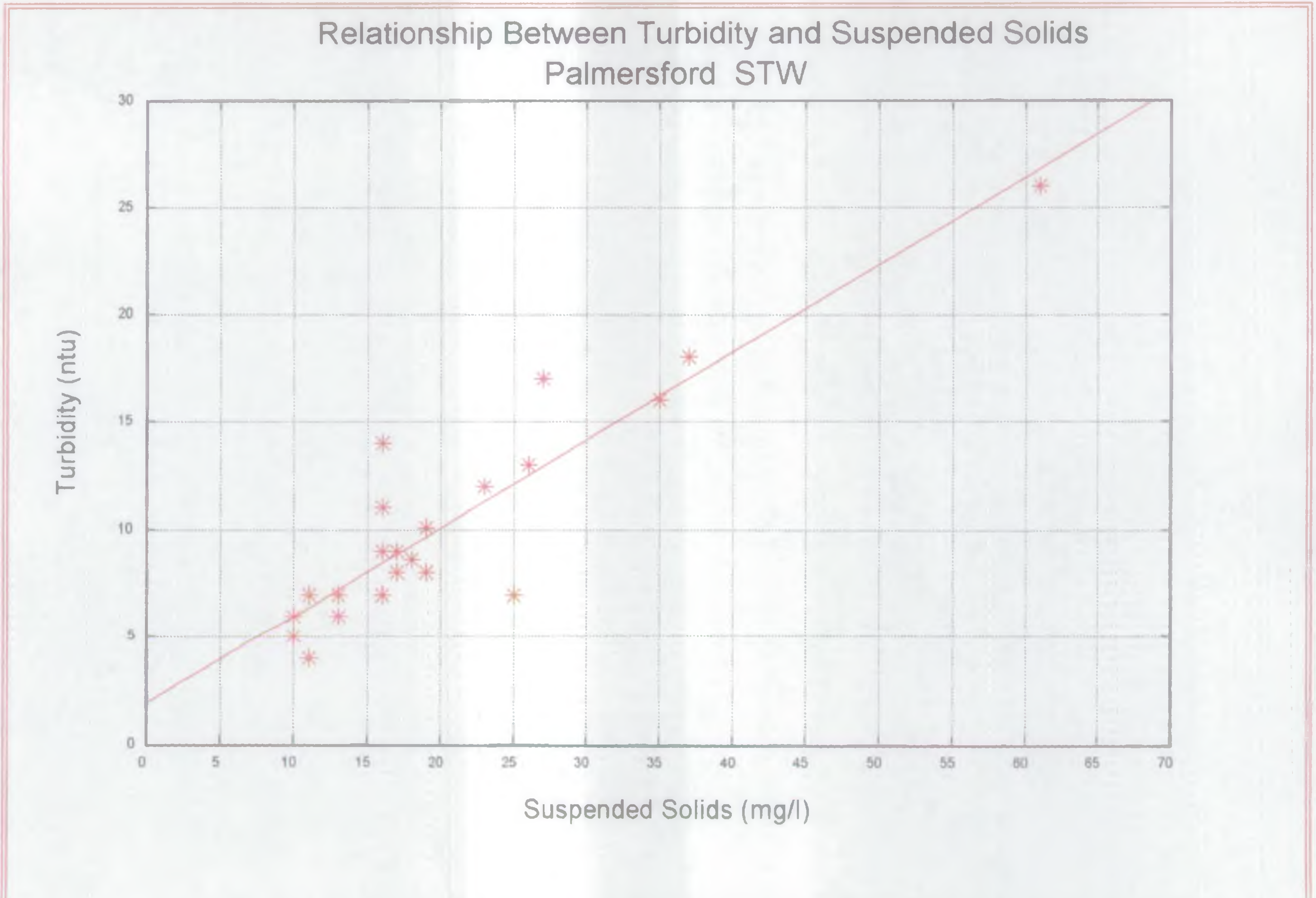

Relationship Between Turbidity and Suspended Solids
Bridgwater STW
Turbidity (ntu)
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
110
120
Suspended Solids (mg/l)

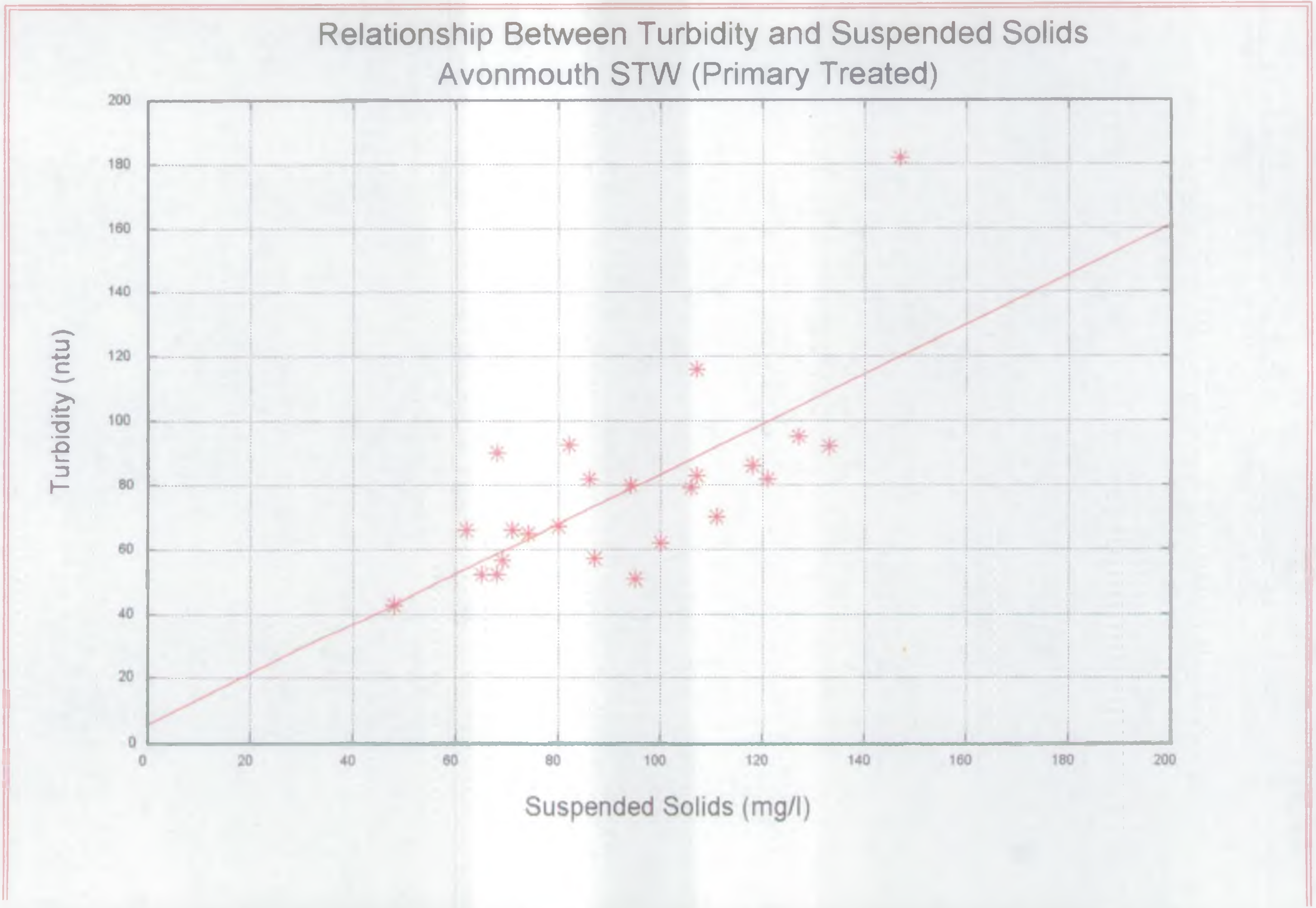

Relationship Between Turbidity and Suspended Solids
Holdenhurst STW
Turbidity (ntu)
Suspended Solids (mg/l)
0
2
4
6
8
10
12
14
16
18
20
22
24

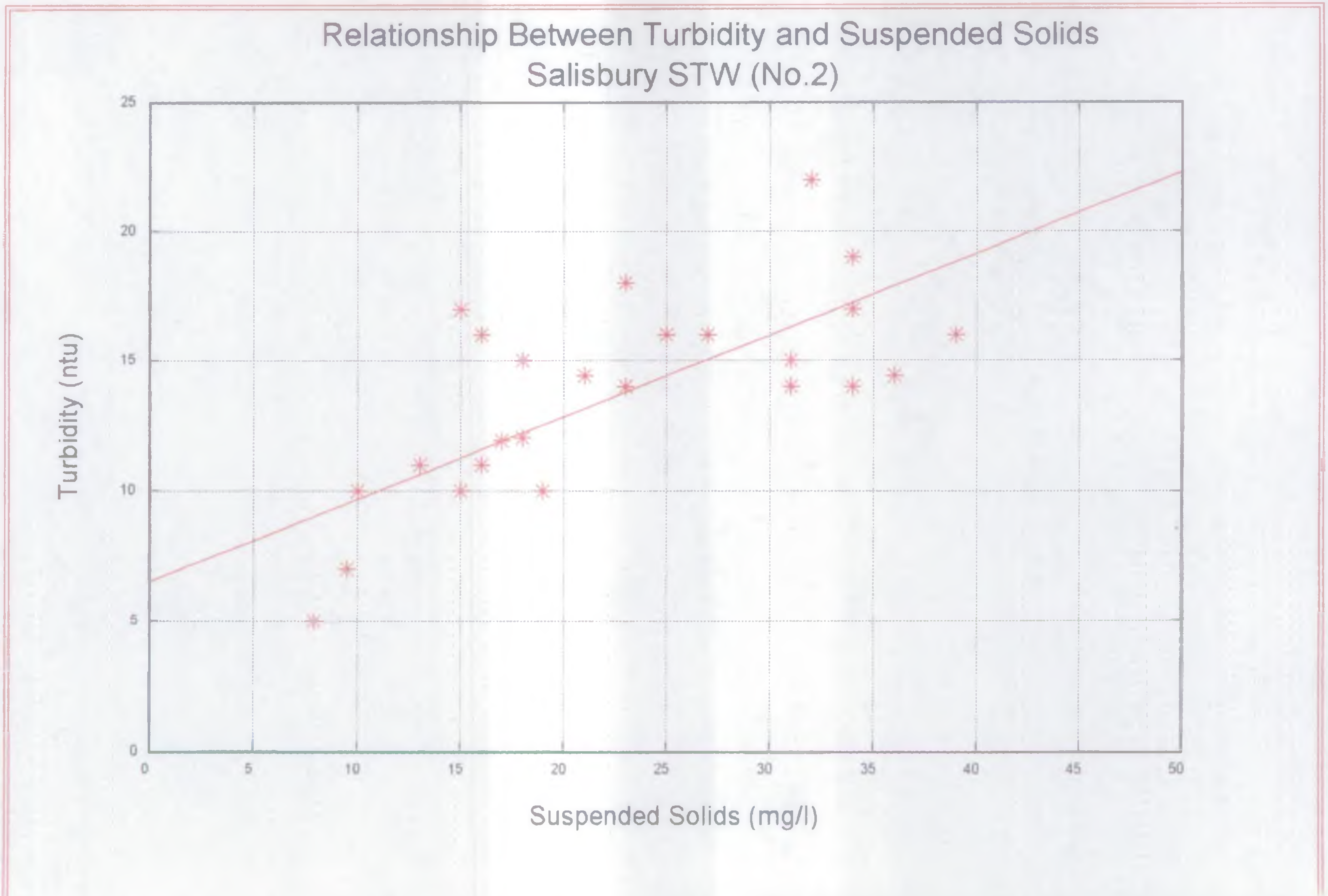


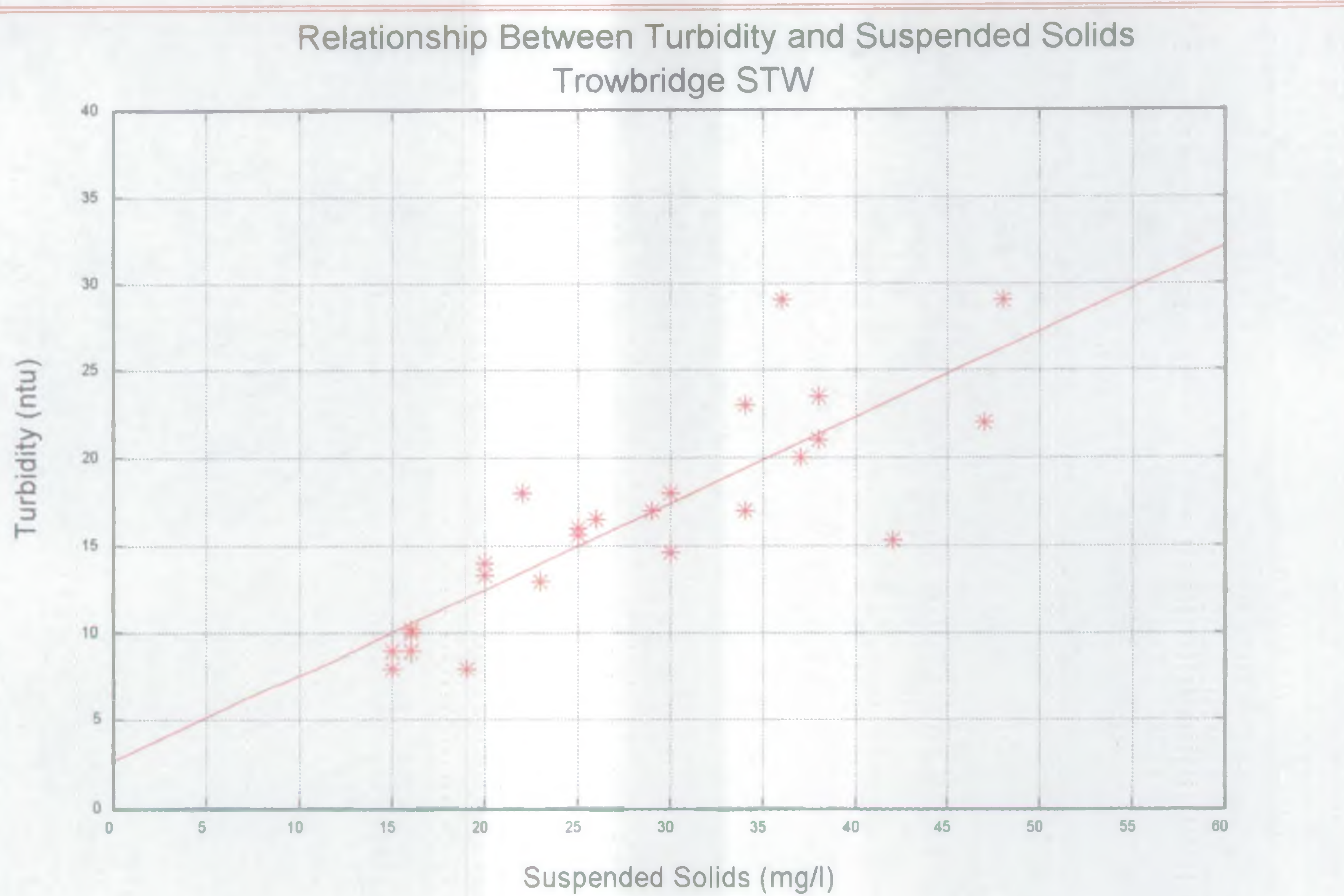
Relationship Between Turbidity and Suspended Solids
Frome STW
Turbidity (ntu)
Suspended Solids (mg/l)
0
2
4
6
8
10
12
14
16
18
20
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80

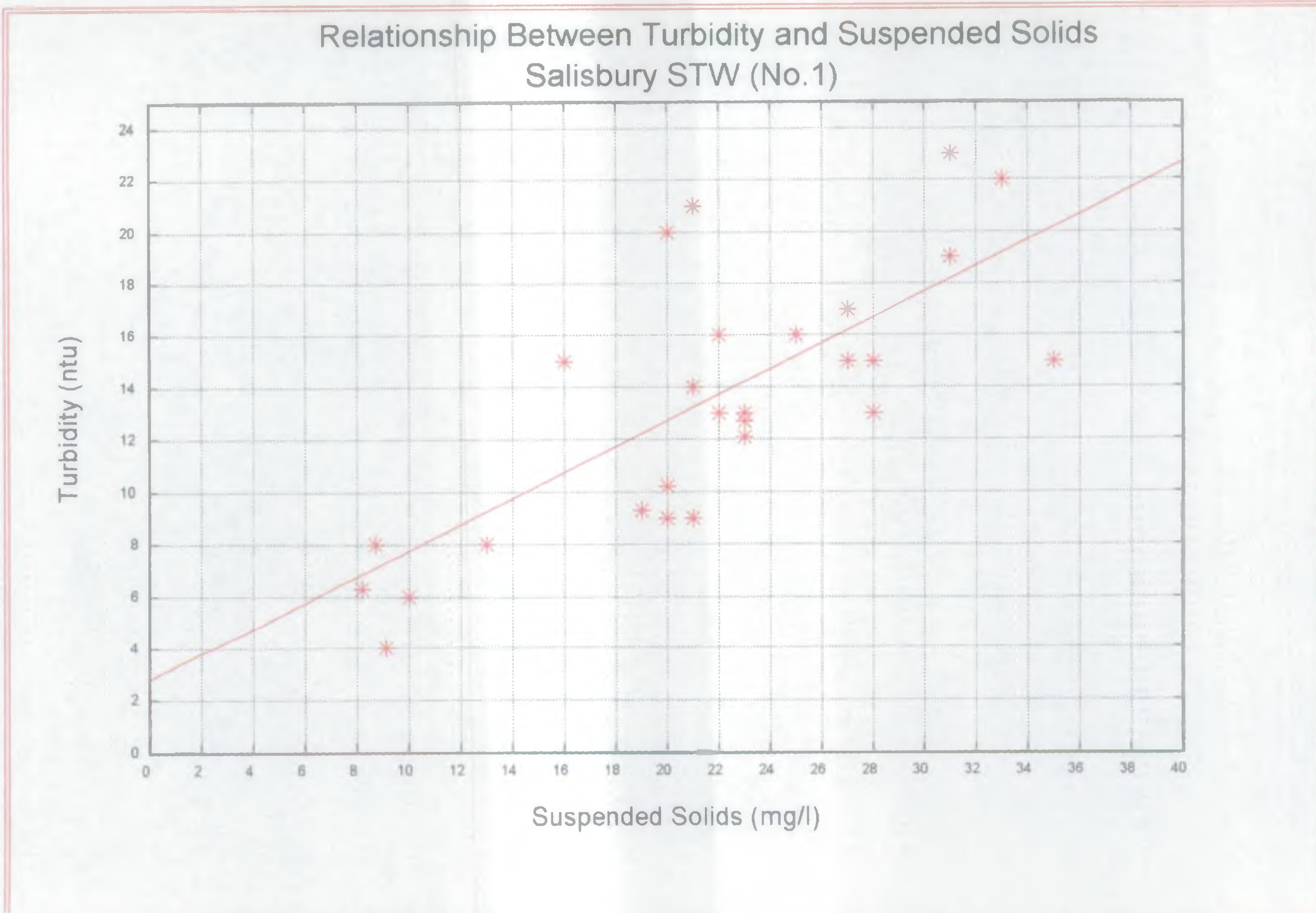

Relationship Between Turbidity and Suspended Solids
Kinson STW
Turbidity (ntu)
Suspended Solids (mg/l)
0
5
10
15
20
25
30
35
40


Relationship Between Turbidity and Suspended Solids
Palmersford STW
Turbidity (ntu)
Suspended Solids (mg/l)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70


Relationship Between Turbidity and Suspended Solids
Avonmouth STW (Primary Treated)
Turbidity (ntu)
Suspended Solids (mg/l)
0
20
40
60
80
100
120
140
160
180
200


Relationship Between Turbidity and Suspended Solids
Salisbury STW (No.2)
Turbidity (ntu)
Suspended Solids (mg/l)
0
5
10
15
20
25
30
35
40
45
50


Relationship Between Turbidity and Suspended Solids
Trowbridge STW
Turbidity (ntu)
0
5
10
15
20
25
30
35
40
0
5
10
15
20
25
30
35
40
45
50
55
60
Suspended Solids (mg/l)


Relationship Between Turbidity and Suspended Solids
Salisbury STW (No.1)
Turbidity (ntu)
0
2
4
6
8
10
12
14
16
18
20
22
24
Suspended Solids (mg/l)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40

Relationship Between Turbidity and Suspended Solids
Saltford STW