Mat-2.177 Seminar on case studies in
operations research

Decision-Making support system for flood control

Environmental Impact Assessment Centre of Finland
Contact person: Arto Inkala

Lauri Kangas
Antti Hovila
Margareetta Ollila
Mikko Vuolanto

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Contents

1 Introduction

1.1 Background

1.1.1 Client - EIA

Environmental Impact Assessment Centre of Finland Ltd. (EIA) is an independent research company. The main aim of the company is to apply state of the art mathematical models for practical demands, and to maintain the validity of models with their continuous development and critical evaluation against field observations. EIA models have been developed for watersheds, rivers, lakes, coastal and sea areas and atmosphere.

This project concerned watershed management and river flood risk analysis. Risk analyses of floods and decision-making support systems for watershed management have become even more important as hydroelectric power plants have become more common.

1.1.2 Case - Yangtze River flood modeling

Yangtze River in China is one largest in the world and some 400 million people live in the area watered by it. There are lots of dams and hydroelectric power plants along the Yangtze. The flow data has been generated for six rivers and for a period of 50 years.

The decision-making situation has two contradicting goals. For maximal productivity of a power plant, the surface of a basin should be as high as possible. The safest situation conversely is that the surface is as low as possible.

1.1.3 Assignment and objectives

EIA formulated the following tasks to the project group:

1. Determine the probability that certain river flows (case Yangtze) exceed maximum tolerance given in 50, 100 and 200 years, provided that long history of the flows is given.
2. Determine optimal actions concerning basin and reserve area usage at every moment with the condition that the risk level is to be less than 0.001. At the strating point all dam and river areas are at their minimum level. Future flows are not known at the decision point.
3. Design a dynamic method or application to produce optimal actions, when costs and risk levels are known.
4. Apply this method to case Yangtze.

EIA delivered us flow data of 6 tributary river of Yangtze, measured daily over 50 years. Also the cost levels of floods, capacity of basins and the delays of fulfillments of the reserve areas were known. The main goal in the project was the design of the decision-making method (mentioned above in 3. task) to aid in taking optimal actions.

1.1.4 Structure of the project

The project can be seen to have consisted of two main parts. The first part was to analyze the flow data given. The first idea was to identify the SARIMA-processes of flows and to estimate the parameters. This would probably be the most suitable approach, but because the assignment was also to calculate probabilities for long term events, we decided not to use time series analysis.

The bigger or at least more relevant part of this project was to analyze the decision-making situation. The goal was to come up with some method, which determines what actions to take under certain conditions.

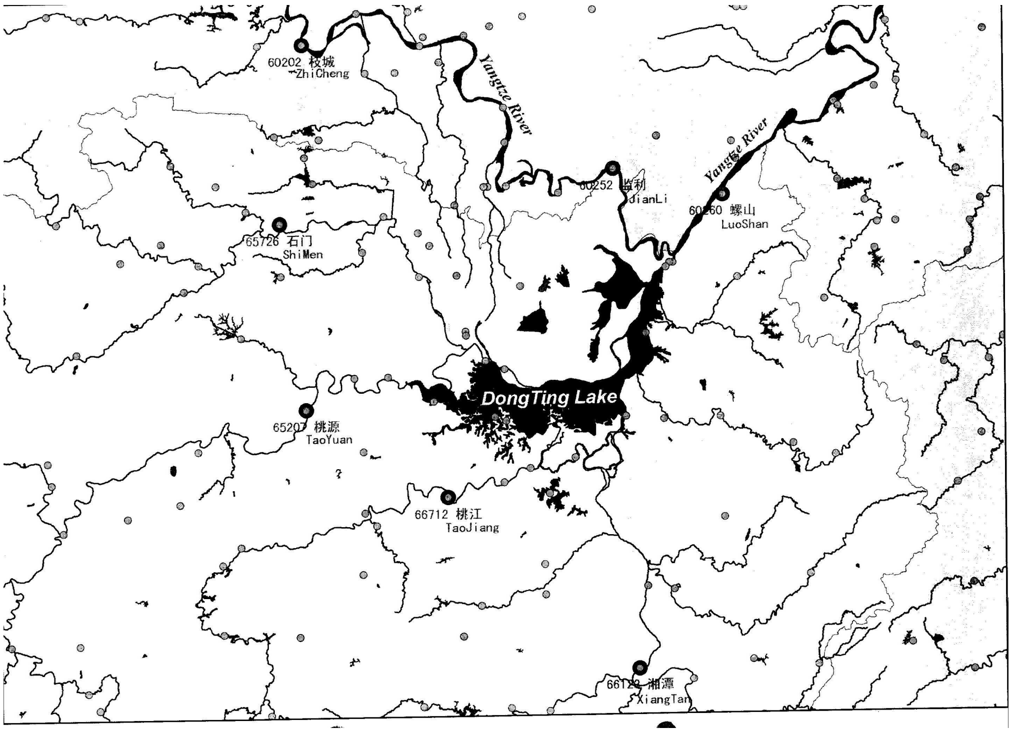


Figure 1: The Yangtze river and the surrounding areas.

1.1.5 Project excecution

The greatest problem in achieving the objectives of the project was that the group worked on a virtual basis. Each member lived in different town and the group communicated mainly through e-mail. This hindered the effectiveness of communication, reduced the exchange of ideas and complicated the execution of the project.

Despite the careful planning of actions in the project the risks in many ways came true. Virtual meetings between team members did not compensate the need for real meetings which all could take place. This hindered in advancing in the project. Afterwards, also the management of the team could have been more dispersed to all the team members.

Since there was only one person really responsable of designing the method to be used in the project case, this would have facilitated the project as well. Much time was also used for clarifying the assigment as well. This could have been easily bypassed by more accurate project information in the beginning of project from EIA.

The co-operation it self worked out fine, both to EIA and within the team. Team spirit was good and open for discussions to solve problems of all kinds. However, there is still much learning to do in project work. Especially the schedule must be carefully followed to able to attain results within the time limits.

1.2 Literature review

The project group carried out a literary review to be aware of the theoretical background of the assignment. When the project was initiated, no one in the project group was familiar with flood modeling or environmental risk analysis. The group discovered that the amount of applicable previous studies on the subject was to some extent limited. Therefore the process of designing the decision-making system was quite intuitive in nature. The most relevant piece of research for designing the decision-making system is presented below.

These studies with different mathematical methods have been done based on different kinds of time series. One aspect is to measure daily rainfall in certain area. More common approach ist to monitor the streamflow, as W. Boughton et al [4] has demonstrated.

Analysing rainfall time series , or any other data than flows, requires a lot more complex analysis, since rainfall and river flows can be rather uncorrelated. In this light, the use of river flow data has a straightforward basis.

Zhang et al (2002) presented an application of an improved linear storage routing model for the estimation of large floods. They emphasized that while conceptual storage routing models have been developed for the same purpose, one of their key components had been the assumed non-linear storage-discharge relationship. In addition, Australian Rainfall and Runoff (Institution of Engineers, 1987) had actually recommended this relationship to be used in the estimation of large floods.

However, also models with other kinds of storage-discharge relationships have been developed. The relationship has been modeled e.g. as asymptotically linear, non-linear with an intercept and as linear. As to which relationship best models the phenomenon, it has been shown that catchments tend to operate as linear systems in larger floods (Zhang, 2001).

In addition, the project group studied articles and literature on flood forecasting (Toth et al., 1998; Strupczewski et al., 2000) and environmental risk analysis in general (Lerche & Paleologos, 2001).

The theoretical approach of this study shared a similar line of thought with the work of Zhang. The theoretical approach will be presented in more detail in subsequent chapters.

1.3 Structure of the report

After this introductory chapter, the decision-making situation will be described in the next chapter. In the third chapter, our approach will be presented in more detail. The chapter also covers the restrictions of our solution and the formulation of the problem. The fourth chapter consists of a discussion of the contribution of the decision-making system. Finally, in the fifth chapter the decision-making system is applied to the case of Yangtze River.

2 Decision situation

The decision situation of systems with many tributary rivers can be divided into parts and each river can be treated independently. In the case of tributary rivers the net effect can be modeled by analysing the sum flows. Thus, every system can be divided into smaller subproblems which can be analyzed as a one basin systems. In future we will concentrate in these so called "one-basin systems".

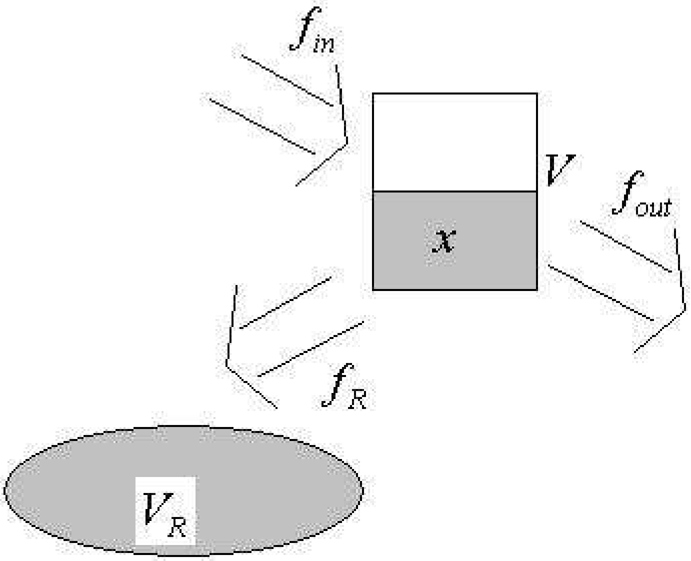


Figure 2: Schematic diagram of a one-basin system. In the middle there is the basin and in the lower left corner the reservoir area.

Assume the basin volume to be V. In the decision situation the current water level of the basin is known. The electricity produced depends linearly on the water level. Assume that the gain of maximum electricity production to be M. There are also an option of using the reservoir area. This involves a non-recurring cost of C. Assume that the volume of the reservoir area is V_R and it fills with constant speed until time T_R (then it's full). If the basin floods, there will be a fine (penalty) of F. The flow put into the river from the basin must not exceed K.

3 Our approach

The data given by EIA of daily measurements made of flow rates from main and tributary rivers from last 50 years leads to use the statistical means in analysing the flood risks. Generally, flow data is typically collected in some form, so our approach presented below is fairly applicable.

In analyzing the river floods the main intrest is to determine the floods probabilities corresponding the decisions made about the basin surface height. We think it is natural to assume that some kind of distributions of the river flows can be estimated. This is also a natural way of approaching the probabilities mentioned above.

This probabilistic approach is easily applied to different kinds of systems, but this generality of course requires simplification of systems.

We approach the decision-making in a following sense: decisions are made discretely at (constant) Δt time intervals. Δt should be chosen small enough, so that this discretation isn't too robust. If $\Delta t \rightarrow 0$ the decision-making is in a sense continous.

3.1 Problem formulation

Naturally the optimization task is to maximize the financial profit of the hydroelectric power plant. If the reservoir usage cost C and flood penalty F are rather small the optimal solution would result from keeping the water level as high as possible throughout the year and accept either the reservoir usage cost C or the flood fine F. To be able to take into account also the humane risks, the risk level itself should also be controlled in some way.

Thus, for humane and political causes it is necessary to add a constraint to keep the risk level low enough. We use a very intuitive constraint, the risk level of the flood must stay below 0.001. Probability P(flood isn't avoidable) is quite hard to calculate, because it consists of the events that flood isn't avoidable and occures at latest at time $t_i, i = 1 \ldots$

This problem can be set aside, because the probabilities that the flood occures much later than now are very small. Thus, the risk level can be approximated by discarding these probabilities.

Denote the degree of fullness of the basin at the time t_n by x_n. Formulating our approach into an optimization problem, at time t_n the decision problem is

$$\begin{aligned} max \quad & M * min(1, E[x_{n+1}]) - (1 - y_{1,n-1}) * y_{1,n} * C - y_{2,n} * F \\ {}^{s.t.} \quad & P(x_{n+1} > 1 \text{ or } x_{n+2} > 1) \leq 0.001 \end{aligned} \tag{1}$$

where,

$x_{n+1} \quad = x_n + (V_{in,n} - V_{out,n})/V, x_n \geq 0$

$V_{in,n}$ is the volume of the water flown into the basin from the river. $V_{in,n}$ is a random variable and thus x_{n+1} is also a random variable.

$V_{out,n}$ is the volume of the water passed through the dam or put into reservoir area. $V_{out,n}$ is a direct consequence of our decisions.

$y_{1,n}$ is the indicator of using the reservoir area, and a decision variable

$y_{2,n}$ is the indicator of flood.

$y_{1,n}$, $y_{2,n}$ and $V_{out,n}$ can be expressed in

$$y_{1,n} = \begin{cases} 1 & \text{,if reservoir area is used} \\ 0 & \text{,otherwise} \end{cases}$$

$$y_{2,n} = \begin{cases} 1 & \text{,if } x_{n+1} > 1 \\ 0 & \text{,otherwise} \end{cases}$$

$$V_{out,n} = f_{out,n} + y_{1,n} * \frac{V_R}{T_R}$$

and $f_{out,n}$ is of course a decision variable, $0 \leq f_{out,n} \leq K$.

3.2 Restrictions

The most obvious restriction of this approach is that some kind of estimated distribution of future river flows are assumed to be available. As already mentioned earlier, this data is although often collected and this restriction isn't at all limiting.

The decision is made discretely and this might be a restriction to some dynamic models. Although the qualitative behaviour of the model should be sufficiently dynamic, when Δt is chosen small enough.

All in all, this approach is in its plainess quite flexible and very applicable to different situations because the main idea is very general.

4 Discussion

This method that has been generated is very straightforward and applicable. There are certain weaknesses or disadvantages concerning the model, and these will be analysed in this section.

4.1 The dynamics of the model

When collecting the data it is important to be sure that the measurements will give an representative sample of the flow or water level behaviour. If the water level is fluctuating all the time, it is possible that the flow maximum will occur between the measurements.

For example if the data is measured daily at noon, but the flow fluctuates throughout the day, the measurements won't give a proper view of the situation. It is also possible that the data isn't representative in the sense that it doesn't show out longer-term effects, e.g. greenhouse effect.

Choosing a good time interval for measurements requires knowledge of the qualitative behaviour of the flood. This time interval is also very closely related to the Δt in the decision-making method. Both intervals should be chosen so that the flows wouldn't fluctuate too much during this interval. It would naturally be suitable to choose this measurement and decision time interval to same Δt.

Analytically it is hard to determine, how small Δt should be for the decision-making to "work". Although, as will be seen later in the case test runs, the river flows maybe quite static and also a big Δt can handle the situation. In the this case example the values for $\Delta t = 1$ day and $\Delta t = 2$ days were tested. When determining a suitable time interval, one should always think how rapidly the river flows change and choose a value for Δt accordingly.

4.2 Estimating the flow distributions

In the method the most binding assumption is that the future flow distributions can be estimated. Even if the estimating can be done, there is uncertainty in the estimates. For example, if the distribution is parametric, the estimated parameter(s) can be biased. This problem dealing with the estimation biases isn't analyzed in this paper, nut being aware of this risk factor can be crucial.

4.3 Calculating the risk levels

The risk level for flood to occur is very hard to calculate, because the inevitable flood can theoretically realize also after a very long period of time. To ease the calculation these probabilities can be cut off and the risk at time t_n can be thought to consist of the events ' The flood occurs at time t_k' , $n \leq k \leq n + m$

These "cut-offs" ease the calculation rapidly, but the disadvantages aren't that big at all. These "tail probabilities" are normally very small.

5 Case Yangtze

5.1 Data analysis

The data was classified both to daily (to 365 cases) and to montly classes. Little surprisingly, none the samples could be identified to be produced by a normal distribution. Instead, the histograms refered to χ^2-distributions. This interesting fact is though as such irrelevant to this decision-making method and no statistical testing was made for this hypothesis. The statistics of sum flow and flow2 are represented in appendices.

Let denote the events
A_i='SUMFLOW doesn't exceed 78500 m^3/s in month i' and
B_i='FLOW2 doesn't exceed 5500 m^3/s in month i.' $i = 1, \ldots, 12$
and $P(A_i) =: p_i$ and $P(B_i) = q_i$. These probabilities can be estimated by histogram method (presented e.g. by Clemen [5]). For example

$$p_1 = 1, q_7 = \Big(\frac{1538}{1550}\Big)^{31} = 0.78589, p_6 = \Big(\frac{1491}{1500}\Big)^{30} = 0.83482$$

Now, probabilities
P(SUMFLOW doesn't exceed 78500 m^3/s in N years)
$= \left(\Pi_{i=1}^{12} p_i^N\right) = (0.88671 * 0.88671 * 0.69621)^N$
P(FLOW2 doesn't exceed 5500 m^3/s in N years)
$= \left(\Pi_{i=1}^{12} q_i^N\right) = (0.88671 * 0.94171 * 0.80189)^N$

Both probabilities are smaller than 10^{-8}, when $N \geq 50$. The fact that these probabilities are very very small isn't that surprising, because we are dealing with very long periods of time. It would, indeed be unexpected that during a 50 year period, there were no floods.

This approach has although a remarkable theoretical weakness: it doesn´t take into account dependencies between daily flows. One could for example imagine that floods last for at least some days. In general, assumption of independent daily flows is hardly true and better approach would be to examine the monthly maximum flows.

This kind of aspect wouldn´t though be applicable for the decision-making mehtod constructed in chapter 3.1. We also supposed that the error caused by this assumption is reasonable and on the other hand it allows the usage of the decision-making method.

5.2 Method demonstration

Now let's demonstrate the decision-making method. The method is applied to one of the tributary rivers of Yangtze. The data is given by EIA and the date is July 10th, 1984. The parameters are as follows:

The basin volume	$V = 1.5 * 10^9 m^3$
The gain from electricity production	$M = 10^6$Eur
Volume of the reservoir area	$V_R = 0.3 * 10^9 m^3$
Cost from using the reservoir area	$C = 50 * 10^6$Eur
The time it takes to full the reservoir area	$T_R = 3$ days
The fine from flood	$F = 500 * 10^6$Eur
The maximum flow in the river	$K = 5500 m^3/s$

Since the data has been given in daily intervals, logical idea is to choose the interval also for the model to be the same, i.e. $\Delta t = 1$ day. Choosing a shorted period would lead to new problemes and it would require further assumptions of the water level change and also the generation of the data for these moments as well. For the sake of researching the effect of Δt same situation is demonstrated with a run of $\Delta t = 2$ days.

At each decision state the problem (1) is solved. It is important to notice that in calculating the risk level, the approximated density function of the $f_{in,n+1}$ is utilized.

The results are rather good and both values for Δt lead to quite similar behaviour. The run with $\Delta t = 2$ days is probably a bit more careful. This is also very intutive, because the variance of $f_{in,n+1}$ is four times as big as with $\Delta t = 1$ day, while the expected value is just twice as big.

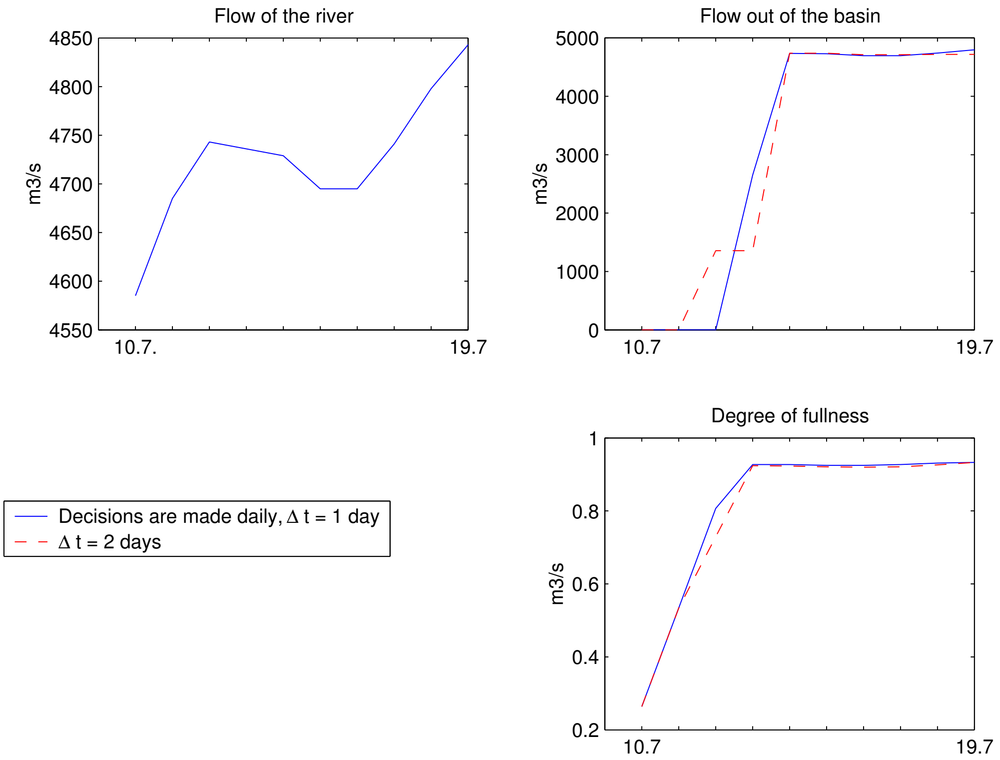


Figure 3: Results of a test run

In both runs the degree of fullness of the basin first grow from 0 to over 0.9 and quickly stabilizes little above 0.9. This method seems to handle this situation fairly well.

References

[1] Lerche I, Paleologos EK (2001): Environmental risk analysis Strupczewski WG, Singh VP, Feluch W (2001): Non-stationary approach to at-site flood frequency modeling I. Maximum likelihood estimation; Journal of Hydrology 248 (2001) 123-142

[2] Toth E, Montanari A, Brath A (1999): Real-Time Flood Forecasting via Combined use of Conceptual and Stochastic Models; Phys. Chem. Earth (B), Vol. 24, No. 7, pp. 793-798

[3] Zhang S, Cordery I, Sharma A (2002): Application of an improved linear storage routing model for the estimation of large floods; Journal of Hydrology 258 (2002) 58-68

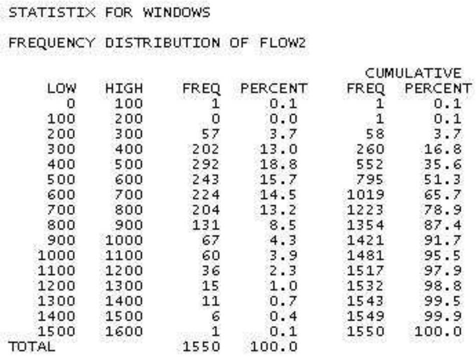
[4] Boughton W, Droop O (2003),Continuous simulation for design flood estimation - a review, Environmental Modelling & Software 18 (2003) pp. 309-318

[5] Clemen, R.T. (1996), Making Hard Decisions: An introduction to Decision Analysis, 2nd Edition, Duxbury, Cambridge.

Appendices

Flow 2 and SUMFLOW data sorted by month.

January



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STATISTIX FOR WINDOWS

FREQUENCY DISTRIBUTION OF FLOW2

                                      CUMULATIVE
     LOW    HIGH     FREQ  PERCENT   FREQ  PERCENT
       0     100        1      0.1      1      0.1
     100     200        0      0.0      1      0.1
     200     300       57      3.7     58      3.7
     300     400      202     13.0    260     16.8
     400     500      292     18.8    552     35.6
     500     600      243     15.7    795     51.3
     600     700      224     14.5   1019     65.7
     700     800      204     13.2   1223     78.9
     800     900      131      8.5   1354     87.4
     900    1000       67      4.3   1421     91.7
    1000    1100       60      3.9   1481     95.5
    1100    1200       36      2.3   1517     97.9
    1200    1300       15      1.0   1532     98.8
    1300    1400       11      0.7   1543     99.5
    1400    1500        6      0.4   1549     99.9
    1500    1600        1      0.1   1550    100.0
TOTAL                1550    100.0
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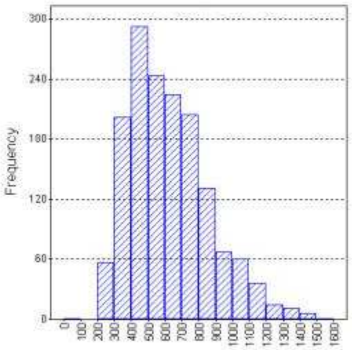

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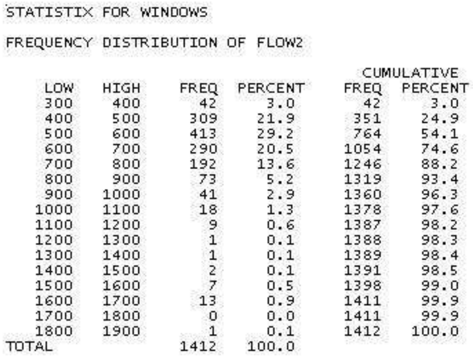

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STATISTIX FOR WINDOWS

FREQUENCY DISTRIBUTION OF FLOW2

                                      CUMULATIVE
     LOW    HIGH     FREQ  PERCENT   FREQ  PERCENT
     300     400       42      3.0     42      3.0
     400     500      309     21.9    351     24.9
     500     600      413     29.2    764     54.1
     600     700      290     20.5   1054     74.6
     700     800      192     13.6   1246     88.2
     800     900       73      5.2   1319     93.4
     900    1000       41      2.9   1360     96.3
    1000    1100       18      1.3   1378     97.6
    1100    1200        9      0.6   1387     98.2
    1200    1300        1      0.1   1388     98.3
    1300    1400        1      0.1   1389     98.4
    1400    1500        2      0.1   1391     98.5
    1500    1600        7      0.5   1398     99.0
    1600    1700       13      0.9   1411     99.9
    1700    1800        0      0.0   1411     99.9
    1800    1900        1      0.1   1412    100.0
TOTAL                1412    100.0
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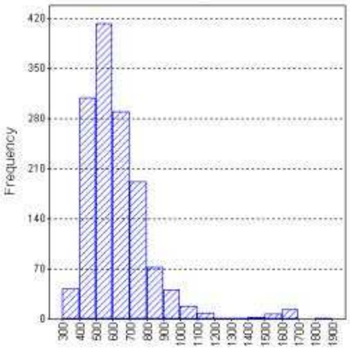

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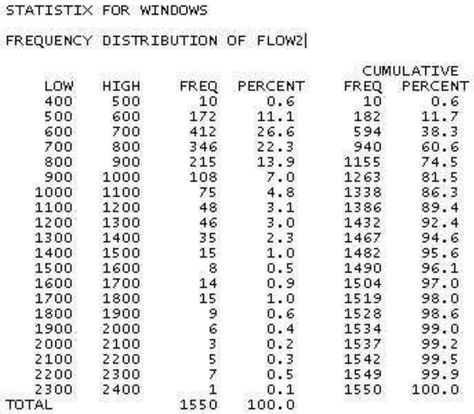

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STATISTIX FOR WINDOWS

FREQUENCY DISTRIBUTION OF FLOW2|

                                      CUMULATIVE
     LOW    HIGH     FREQ  PERCENT   FREQ  PERCENT
     400     500       10      0.6     10      0.6
     500     600      172     11.1    182     11.7
     600     700      412     26.6    594     38.3
     700     800      346     22.3    940     60.6
     800     900      215     13.9   1155     74.5
     900    1000      108      7.0   1263     81.5
    1000    1100       75      4.8   1338     86.3
    1100    1200       48      3.1   1386     89.4
    1200    1300       46      3.0   1432     92.4
    1300    1400       35      2.3   1467     94.6
    1400    1500       15      1.0   1482     95.6
    1500    1600        8      0.5   1490     96.1
    1600    1700       14      0.9   1504     97.0
    1700    1800       15      1.0   1519     98.0
    1800    1900        9      0.6   1528     98.6
    1900    2000        6      0.4   1534     99.0
    2000    2100        3      0.2   1537     99.2
    2100    2200        5      0.3   1542     99.5
    2200    2300        7      0.5   1549     99.9
    2300    2400        1      0.1   1550    100.0
TOTAL                1550    100.0
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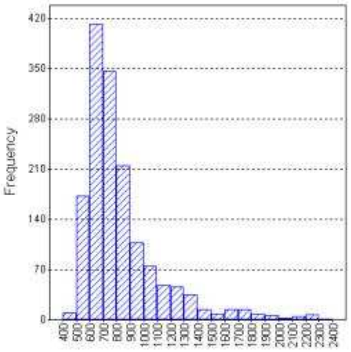

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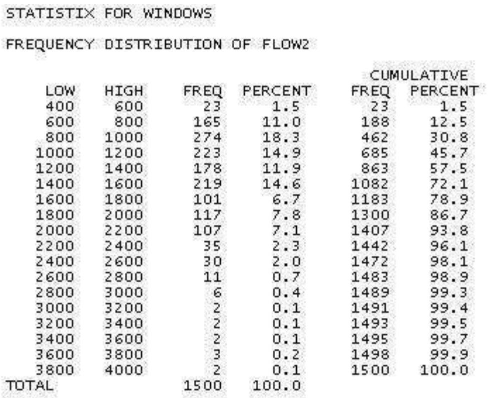

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STATISTIX FOR WINDOWS

FREQUENCY DISTRIBUTION OF FLOW2

                                        CUMULATIVE
    LOW    HIGH     FREQ  PERCENT     FREQ  PERCENT
    400     600       23      1.5       23      1.5
    600     800      165     11.0      188     12.5
    800    1000      274     18.3      462     30.8
   1000    1200      223     14.9      685     45.7
   1200    1400      178     11.9      863     57.5
   1400    1600      219     14.6     1082     72.1
   1600    1800      101      6.7     1183     78.9
   1800    2000      117      7.8     1300     86.7
   2000    2200      107      7.1     1407     93.8
   2200    2400       35      2.3     1442     96.1
   2400    2600       30      2.0     1472     98.1
   2600    2800       11      0.7     1483     98.9
   2800    3000        6      0.4     1489     99.3
   3000    3200        2      0.1     1491     99.4
   3200    3400        2      0.1     1493     99.5
   3400    3600        2      0.1     1495     99.7
   3600    3800        3      0.2     1498     99.9
   3800    4000        2      0.1     1500    100.0
TOTAL               1500    100.0
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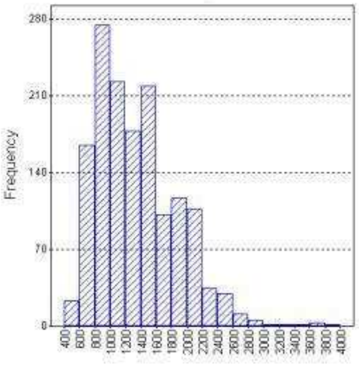

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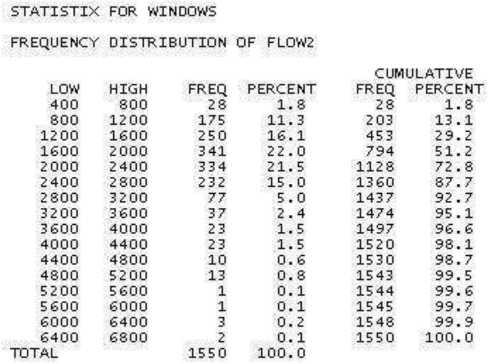

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STATISTIX FOR WINDOWS

FREQUENCY DISTRIBUTION OF FLOW2

                                        CUMULATIVE
    LOW    HIGH     FREQ  PERCENT     FREQ  PERCENT
    400     800       28      1.8       28      1.8
    800    1200      175     11.3      203     13.1
   1200    1600      250     16.1      453     29.2
   1600    2000      341     22.0      794     51.2
   2000    2400      334     21.5     1128     72.8
   2400    2800      232     15.0     1360     87.7
   2800    3200       77      5.0     1437     92.7
   3200    3600       37      2.4     1474     95.1
   3600    4000       23      1.5     1497     96.6
   4000    4400       23      1.5     1520     98.1
   4400    4800       10      0.6     1530     98.7
   4800    5200       13      0.8     1543     99.5
   5200    5600        1      0.1     1544     99.6
   5600    6000        1      0.1     1545     99.7
   6000    6400        3      0.2     1548     99.9
   6400    6800        2      0.1     1550    100.0
TOTAL               1550    100.0
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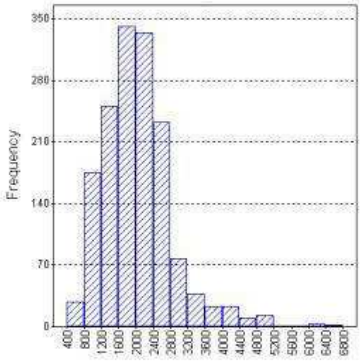
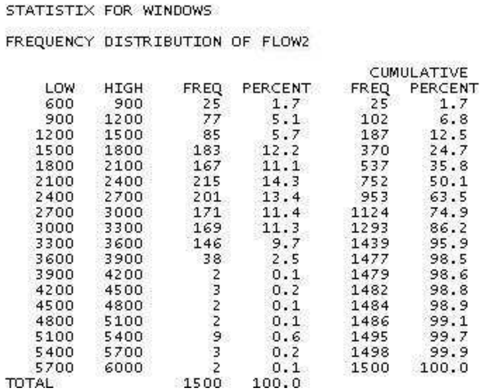


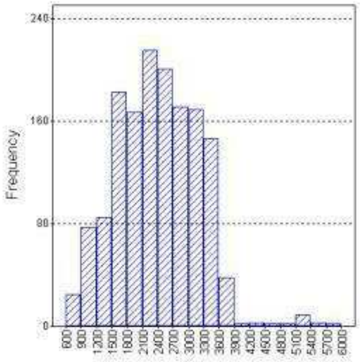
June



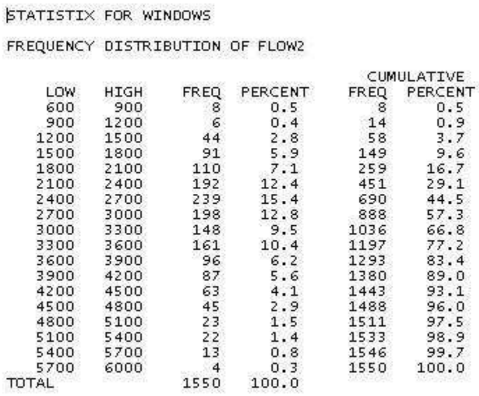
```
STATISTIX FOR WINDOWS

FREQUENCY DISTRIBUTION OF FLOW2

                                        CUMULATIVE
    LOW    HIGH     FREQ  PERCENT     FREQ  PERCENT
    600     900       25      1.7       25      1.7
    900    1200       77      5.1      102      6.8
   1200    1500       85      5.7      187     12.5
   1500    1800      183     12.2      370     24.7
   1800    2100      167     11.1      537     35.8
   2100    2400      215     14.3      752     50.1
   2400    2700      201     13.4      953     63.5
   2700    3000      171     11.4     1124     74.9
   3000    3300      169     11.3     1293     86.2
   3300    3600      146      9.7     1439     95.9
   3600    3900       38      2.5     1477     98.5
   3900    4200        2      0.1     1479     98.6
   4200    4500        3      0.2     1482     98.8
   4500    4800        2      0.1     1484     98.9
   4800    5100        2      0.1     1486     99.1
   5100    5400        9      0.6     1495     99.7
   5400    5700        3      0.2     1498     99.9
   5700    6000        2      0.1     1500    100.0
TOTAL               1500    100.0
```



July

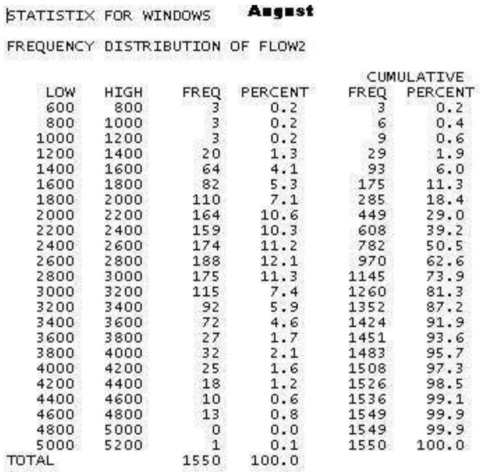


```
STATISTIX FOR WINDOWS

FREQUENCY DISTRIBUTION OF FLOW2

                                      CUMULATIVE
   LOW    HIGH      FREQ  PERCENT    FREQ  PERCENT
   600     900         8      0.5       8      0.5
   900    1200         6      0.4      14      0.9
  1200    1500        44      2.8      58      3.7
  1500    1800        91      5.9     149      9.6
  1800    2100       110      7.1     259     16.7
  2100    2400       192     12.4     451     29.1
  2400    2700       239     15.4     690     44.5
  2700    3000       198     12.8     888     57.3
  3000    3300       148      9.5    1036     66.8
  3300    3600       161     10.4    1197     77.2
  3600    3900        96      6.2    1293     83.4
  3900    4200        87      5.6    1380     89.0
  4200    4500        63      4.1    1443     93.1
  4500    4800        45      2.9    1488     96.0
  4800    5100        23      1.5    1511     97.5
  5100    5400        22      1.4    1533     98.9
  5400    5700        13      0.8    1546     99.7
  5700    6000         4      0.3    1550    100.0
TOTAL                 1550    100.0
```

August

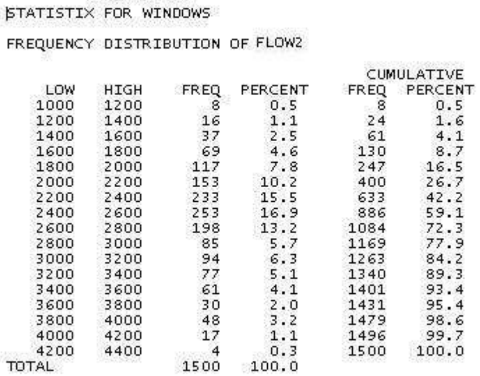


```
STATISTIX FOR WINDOWS

FREQUENCY DISTRIBUTION OF FLOW2

                                      CUMULATIVE
   LOW    HIGH      FREQ  PERCENT    FREQ  PERCENT
   600     800         3      0.2       3      0.2
   800    1000         3      0.2       6      0.4
  1000    1200         3      0.2       9      0.6
  1200    1400        20      1.3      29      1.9
  1400    1600        64      4.1      93      6.0
  1600    1800        82      5.3     175     11.3
  1800    2000       110      7.1     285     18.4
  2000    2200       164     10.6     449     29.0
  2200    2400       159     10.3     608     39.2
  2400    2600       174     11.2     782     50.5
  2600    2800       188     12.1     970     62.6
  2800    3000       175     11.3    1145     73.9
  3000    3200       115      7.4    1260     81.3
  3200    3400        92      5.9    1352     87.2
  3400    3600        72      4.6    1424     91.9
  3600    3800        27      1.7    1451     93.6
  3800    4000        32      2.1    1483     95.7
  4000    4200        25      1.6    1508     97.3
  4200    4400        18      1.2    1526     98.5
  4400    4600        10      0.6    1536     99.1
  4600    4800        13      0.8    1549     99.9
  4800    5000         0      0.0    1549     99.9
  5000    5200         1      0.1    1550    100.0
TOTAL                 1550    100.0
```

September



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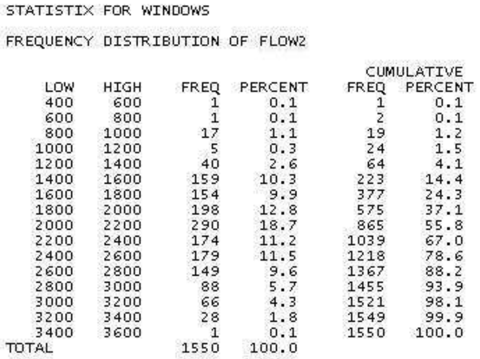
STATISTIX FOR WINDOWS

FREQUENCY DISTRIBUTION OF FLOW2

                                      CUMULATIVE
   LOW    HIGH      FREQ  PERCENT    FREQ  PERCENT
  1000    1200         8      0.5       8      0.5
  1200    1400        16      1.1      24      1.6
  1400    1600        37      2.5      61      4.1
  1600    1800        69      4.6     130      8.7
  1800    2000       117      7.8     247     16.5
  2000    2200       153     10.2     400     26.7
  2200    2400       233     15.5     633     42.2
  2400    2600       253     16.9     886     59.1
  2600    2800       198     13.2    1084     72.3
  2800    3000        85      5.7    1169     77.9
  3000    3200        94      6.3    1263     84.2
  3200    3400        77      5.1    1340     89.3
  3400    3600        61      4.1    1401     93.4
  3600    3800        30      2.0    1431     95.4
  3800    4000        48      3.2    1479     98.6
  4000    4200        17      1.1    1496     99.7
  4200    4400         4      0.3    1500    100.0
TOTAL                 1500    100.0
```

October



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STATISTIX FOR WINDOWS

FREQUENCY DISTRIBUTION OF FLOW2

                                      CUMULATIVE
   LOW    HIGH      FREQ  PERCENT    FREQ  PERCENT
   400     600         1      0.1       1      0.1
   600     800         1      0.1       2      0.1
   800    1000        17      1.1      19      1.2
  1000    1200         5      0.3      24      1.5
  1200    1400        40      2.6      64      4.1
  1400    1600       159     10.3     223     14.4
  1600    1800       154      9.9     377     24.3
  1800    2000       198     12.8     575     37.1
  2000    2200       290     18.7     865     55.8
  2200    2400       174     11.2    1039     67.0
  2400    2600       179     11.5    1218     78.6
  2600    2800       149      9.6    1367     88.2
  2800    3000        88      5.7    1455     93.9
  3000    3200        66      4.3    1521     98.1
  3200    3400        28      1.8    1549     99.9
  3400    3600         1      0.1    1550    100.0
TOTAL                 1550    100.0
```
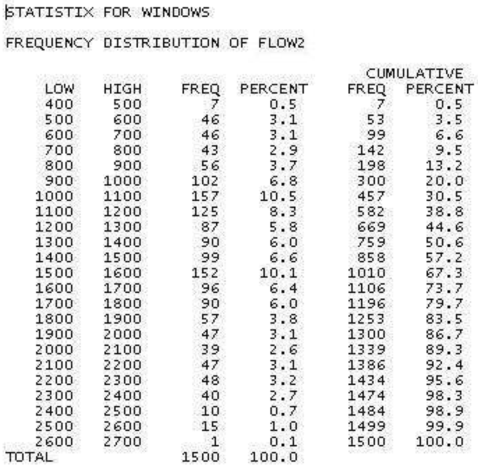

November



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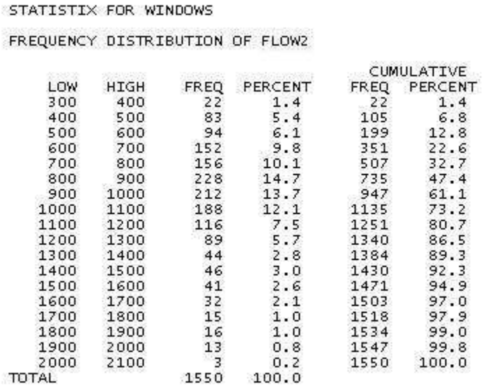
STATISTIX FOR WINDOWS

FREQUENCY DISTRIBUTION OF FLOW2

                                      CUMULATIVE
   LOW    HIGH      FREQ  PERCENT    FREQ  PERCENT
   400     500         7      0.5       7      0.5
   500     600        46      3.1      53      3.5
   600     700        46      3.1      99      6.6
   700     800        43      2.9     142      9.5
   800     900        56      3.7     198     13.2
   900    1000       102      6.8     300     20.0
  1000    1100       157     10.5     457     30.5
  1100    1200       125      8.3     582     38.8
  1200    1300        87      5.8     669     44.6
  1300    1400        90      6.0     759     50.6
  1400    1500        99      6.6     858     57.2
  1500    1600       152     10.1    1010     67.3
  1600    1700        96      6.4    1106     73.7
  1700    1800        90      6.0    1196     79.7
  1800    1900        57      3.8    1253     83.5
  1900    2000        47      3.1    1300     86.7
  2000    2100        39      2.6    1339     89.3
  2100    2200        47      3.1    1386     92.4
  2200    2300        48      3.2    1434     95.6
  2300    2400        40      2.7    1474     98.3
  2400    2500        10      0.7    1484     98.9
  2500    2600        15      1.0    1499     99.9
  2600    2700         1      0.1    1500    100.0
TOTAL                 1500    100.0
```

December



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STATISTIX FOR WINDOWS

FREQUENCY DISTRIBUTION OF FLOW2

                                      CUMULATIVE
   LOW    HIGH      FREQ  PERCENT    FREQ  PERCENT
   300     400        22      1.4      22      1.4
   400     500        83      5.4     105      6.8
   500     600        94      6.1     199     12.8
   600     700       152      9.8     351     22.6
   700     800       156     10.1     507     32.7
   800     900       228     14.7     735     47.4
   900    1000       212     13.7     947     61.1
  1000    1100       188     12.1    1135     73.2
  1100    1200       116      7.5    1251     80.7
  1200    1300        89      5.7    1340     86.5
  1300    1400        44      2.8    1384     89.3
  1400    1500        46      3.0    1430     92.3
  1500    1600        41      2.6    1471     94.9
  1600    1700        32      2.1    1503     97.0
  1700    1800        15      1.0    1518     97.9
  1800    1900        16      1.0    1534     99.0
  1900    2000        13      0.8    1547     99.8
  2000    2100         3      0.2    1550    100.0
TOTAL                 1550    100.0
```

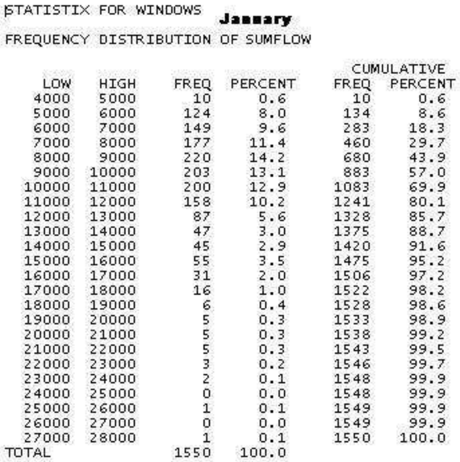

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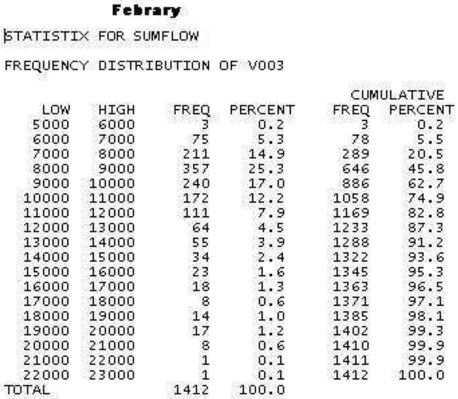
STATISTIX FOR WINDOWS      January
FREQUENCY DISTRIBUTION OF SUMFLOW

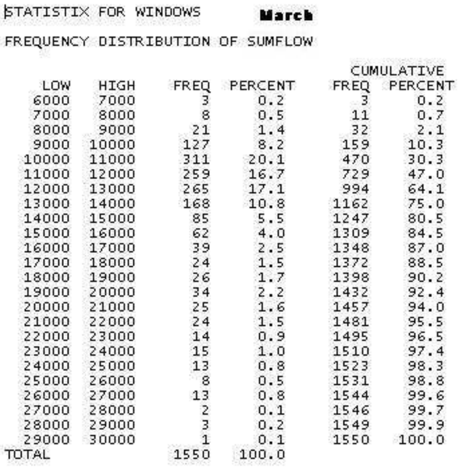
                                          CUMULATIVE
    LOW    HIGH      FREQ  PERCENT      FREQ  PERCENT
   4000    5000        10      0.6        10      0.6
   5000    6000       124      8.0       134      8.6
   6000    7000       149      9.6       283     18.3
   7000    8000       177     11.4       460     29.7
   8000    9000       220     14.2       680     43.9
   9000   10000       203     13.1       883     57.0
  10000   11000       200     12.9      1083     69.9
  11000   12000       158     10.2      1241     80.1
  12000   13000        87      5.6      1328     85.7
  13000   14000        47      3.0      1375     88.7
  14000   15000        45      2.9      1420     91.6
  15000   16000        55      3.5      1475     95.2
  16000   17000        31      2.0      1506     97.2
  17000   18000        16      1.0      1522     98.2
  18000   19000         6      0.4      1528     98.6
  19000   20000         5      0.3      1533     98.9
  20000   21000         5      0.3      1538     99.2
  21000   22000         5      0.3      1543     99.5
  22000   23000         3      0.2      1546     99.7
  23000   24000         2      0.1      1548     99.9
  24000   25000         0      0.0      1548     99.9
  25000   26000         1      0.1      1549     99.9
  26000   27000         0      0.0      1549     99.9
  27000   28000         1      0.1      1550    100.0
TOTAL                1550    100.0
```



```
                Febrary
STATISTIX FOR SUMFLOW

FREQUENCY DISTRIBUTION OF V003

                                          CUMULATIVE
    LOW    HIGH      FREQ  PERCENT      FREQ  PERCENT
   5000    6000         3      0.2         3      0.2
   6000    7000        75      5.3        78      5.5
   7000    8000       211     14.9       289     20.5
   8000    9000       357     25.3       646     45.8
   9000   10000       240     17.0       886     62.7
  10000   11000       172     12.2      1058     74.9
  11000   12000       111      7.9      1169     82.8
  12000   13000        64      4.5      1233     87.3
  13000   14000        55      3.9      1288     91.2
  14000   15000        34      2.4      1322     93.6
  15000   16000        23      1.6      1345     95.3
  16000   17000        18      1.3      1363     96.5
  17000   18000         8      0.6      1371     97.1
  18000   19000        14      1.0      1385     98.1
  19000   20000        17      1.2      1402     99.3
  20000   21000         8      0.6      1410     99.9
  21000   22000         1      0.1      1411     99.9
  22000   23000         1      0.1      1412    100.0
TOTAL                1412    100.0
```



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STATISTIX FOR WINDOWS          March

FREQUENCY DISTRIBUTION OF SUMFLOW

                                          CUMULATIVE
    LOW    HIGH      FREQ  PERCENT      FREQ  PERCENT
   6000    7000         3      0.2         3      0.2
   7000    8000         8      0.5        11      0.7
   8000    9000        21      1.4        32      2.1
   9000   10000       127      8.2       159     10.3
  10000   11000       311     20.1       470     30.3
  11000   12000       259     16.7       729     47.0
  12000   13000       265     17.1       994     64.1
  13000   14000       168     10.8      1162     75.0
  14000   15000        85      5.5      1247     80.5
  15000   16000        62      4.0      1309     84.5
  16000   17000        39      2.5      1348     87.0
  17000   18000        24      1.5      1372     88.5
  18000   19000        26      1.7      1398     90.2
  19000   20000        34      2.2      1432     92.4
  20000   21000        25      1.6      1457     94.0
  21000   22000        24      1.5      1481     95.5
  22000   23000        14      0.9      1495     96.5
  23000   24000        15      1.0      1510     97.4
  24000   25000        13      0.8      1523     98.3
  25000   26000         8      0.5      1531     98.8
  26000   27000        13      0.8      1544     99.6
  27000   28000         2      0.1      1546     99.7
  28000   29000         3      0.2      1549     99.9
  29000   30000         1      0.1      1550    100.0
TOTAL                1550    100.0
```

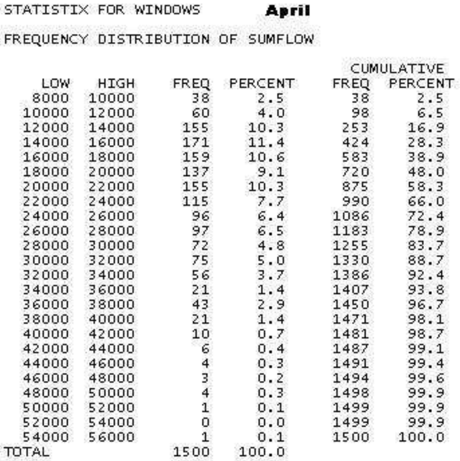

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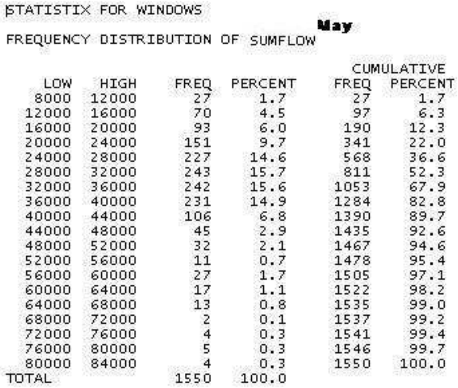
STATISTIX FOR WINDOWS          April

FREQUENCY DISTRIBUTION OF SUMFLOW

                                          CUMULATIVE
    LOW    HIGH      FREQ  PERCENT      FREQ  PERCENT
   8000   10000        38      2.5        38      2.5
  10000   12000        60      4.0        98      6.5
  12000   14000       155     10.3       253     16.9
  14000   16000       171     11.4       424     28.3
  16000   18000       159     10.6       583     38.9
  18000   20000       137      9.1       720     48.0
  20000   22000       155     10.3       875     58.3
  22000   24000       115      7.7       990     66.0
  24000   26000        96      6.4      1086     72.4
  26000   28000        97      6.5      1183     78.9
  28000   30000        72      4.8      1255     83.7
  30000   32000        75      5.0      1330     88.7
  32000   34000        56      3.7      1386     92.4
  34000   36000        21      1.4      1407     93.8
  36000   38000        43      2.9      1450     96.7
  38000   40000        21      1.4      1471     98.1
  40000   42000        10      0.7      1481     98.7
  42000   44000         6      0.4      1487     99.1
  44000   46000         4      0.3      1491     99.4
  46000   48000         3      0.2      1494     99.6
  48000   50000         4      0.3      1498     99.9
  50000   52000         1      0.1      1499     99.9
  52000   54000         0      0.0      1499     99.9
  54000   56000         1      0.1      1500    100.0
TOTAL                1500    100.0
```



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STATISTIX FOR WINDOWS
                                     May
FREQUENCY DISTRIBUTION OF SUMFLOW

                                          CUMULATIVE
    LOW    HIGH      FREQ  PERCENT      FREQ  PERCENT
   8000   12000        27      1.7        27      1.7
  12000   16000        70      4.5        97      6.3
  16000   20000        93      6.0       190     12.3
  20000   24000       151      9.7       341     22.0
  24000   28000       227     14.6       568     36.6
  28000   32000       243     15.7       811     52.3
  32000   36000       242     15.6      1053     67.9
  36000   40000       231     14.9      1284     82.8
  40000   44000       106      6.8      1390     89.7
  44000   48000        45      2.9      1435     92.6
  48000   52000        32      2.1      1467     94.6
  52000   56000        11      0.7      1478     95.4
  56000   60000        27      1.7      1505     97.1
  60000   64000        17      1.1      1522     98.2
  64000   68000        13      0.8      1535     99.0
  68000   72000         2      0.1      1537     99.2
  72000   76000         4      0.3      1541     99.4
  76000   80000         5      0.3      1546     99.7
  80000   84000         4      0.3      1550    100.0
TOTAL                1550    100.0
```

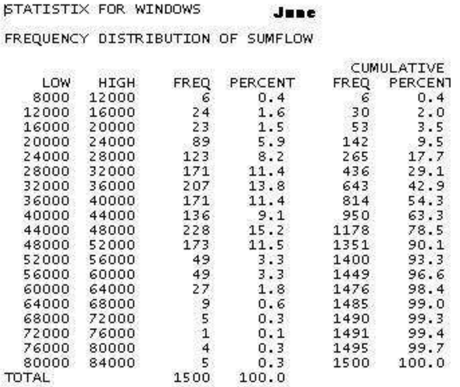

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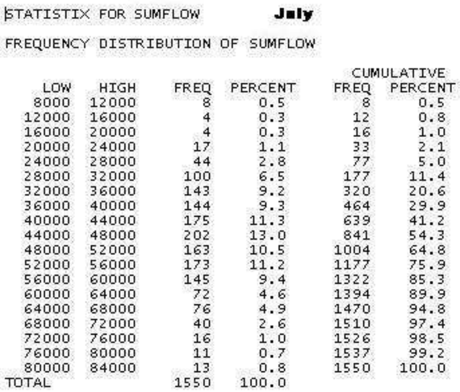
STATISTIX FOR WINDOWS           June

FREQUENCY DISTRIBUTION OF SUMFLOW

                                          CUMULATIVE
    LOW    HIGH      FREQ  PERCENT      FREQ  PERCENT
   8000   12000         6      0.4         6      0.4
  12000   16000        24      1.6        30      2.0
  16000   20000        23      1.5        53      3.5
  20000   24000        89      5.9       142      9.5
  24000   28000       123      8.2       265     17.7
  28000   32000       171     11.4       436     29.1
  32000   36000       207     13.8       643     42.9
  36000   40000       171     11.4       814     54.3
  40000   44000       136      9.1       950     63.3
  44000   48000       228     15.2      1178     78.5
  48000   52000       173     11.5      1351     90.1
  52000   56000        49      3.3      1400     93.3
  56000   60000        49      3.3      1449     96.6
  60000   64000        27      1.8      1476     98.4
  64000   68000         9      0.6      1485     99.0
  68000   72000         5      0.3      1490     99.3
  72000   76000         1      0.1      1491     99.4
  76000   80000         4      0.3      1495     99.7
  80000   84000         5      0.3      1500    100.0
TOTAL                1500    100.0
```



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STATISTIX FOR SUMFLOW          July

FREQUENCY DISTRIBUTION OF SUMFLOW

                                        CUMULATIVE
   LOW    HIGH      FREQ  PERCENT      FREQ  PERCENT
  8000   12000         8      0.5         8      0.5
 12000   16000         4      0.3        12      0.8
 16000   20000         4      0.3        16      1.0
 20000   24000        17      1.1        33      2.1
 24000   28000        44      2.8        77      5.0
 28000   32000       100      6.5       177     11.4
 32000   36000       143      9.2       320     20.6
 36000   40000       144      9.3       464     29.9
 40000   44000       175     11.3       639     41.2
 44000   48000       202     13.0       841     54.3
 48000   52000       163     10.5      1004     64.8
 52000   56000       173     11.2      1177     75.9
 56000   60000       145      9.4      1322     85.3
 60000   64000        72      4.6      1394     89.9
 64000   68000        76      4.9      1470     94.8
 68000   72000        40      2.6      1510     97.4
 72000   76000        16      1.0      1526     98.5
 76000   80000        11      0.7      1537     99.2
 80000   84000        13      0.8      1550    100.0
TOTAL               1550    100.0
```
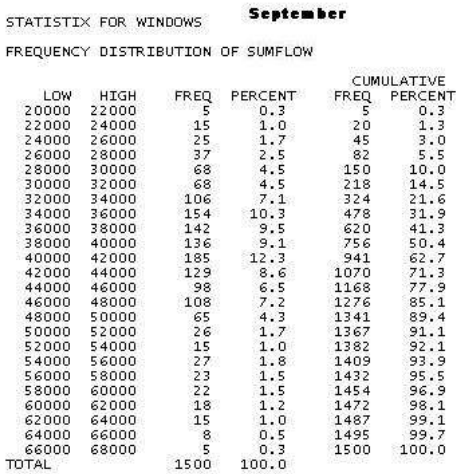
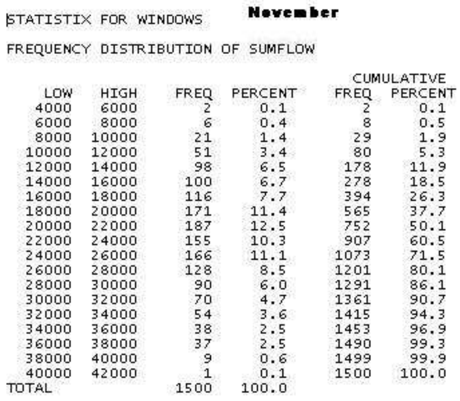



```
STATISTIX FOR WINDOWS          September

FREQUENCY DISTRIBUTION OF SUMFLOW

                                        CUMULATIVE
   LOW    HIGH      FREQ  PERCENT      FREQ  PERCENT
 20000   22000         5      0.3         5      0.3
 22000   24000        15      1.0        20      1.3
 24000   26000        25      1.7        45      3.0
 26000   28000        37      2.5        82      5.5
 28000   30000        68      4.5       150     10.0
 30000   32000        68      4.5       218     14.5
 32000   34000       106      7.1       324     21.6
 34000   36000       154     10.3       478     31.9
 36000   38000       142      9.5       620     41.3
 38000   40000       136      9.1       756     50.4
 40000   42000       185     12.3       941     62.7
 42000   44000       129      8.6      1070     71.3
 44000   46000        98      6.5      1168     77.9
 46000   48000       108      7.2      1276     85.1
 48000   50000        65      4.3      1341     89.4
 50000   52000        26      1.7      1367     91.1
 52000   54000        15      1.0      1382     92.1
 54000   56000        27      1.8      1409     93.9
 56000   58000        23      1.5      1432     95.5
 58000   60000        22      1.5      1454     96.9
 60000   62000        18      1.2      1472     98.1
 62000   64000        15      1.0      1487     99.1
 64000   66000         8      0.5      1495     99.7
 66000   68000         5      0.3      1500    100.0
TOTAL               1500    100.0
```



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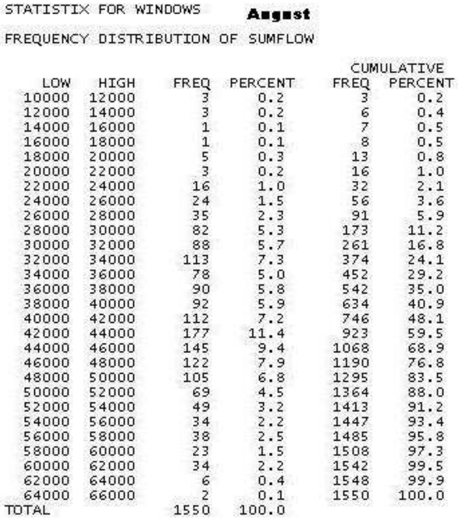
STATISTIX FOR WINDOWS          November

FREQUENCY DISTRIBUTION OF SUMFLOW

                                        CUMULATIVE
   LOW    HIGH      FREQ  PERCENT      FREQ  PERCENT
  4000    6000         2      0.1         2      0.1
  6000    8000         6      0.4         8      0.5
  8000   10000        21      1.4        29      1.9
 10000   12000        51      3.4        80      5.3
 12000   14000        98      6.5       178     11.9
 14000   16000       100      6.7       278     18.5
 16000   18000       116      7.7       394     26.3
 18000   20000       171     11.4       565     37.7
 20000   22000       187     12.5       752     50.1
 22000   24000       155     10.3       907     60.5
 24000   26000       166     11.1      1073     71.5
 26000   28000       128      8.5      1201     80.1
 28000   30000        90      6.0      1291     86.1
 30000   32000        70      4.7      1361     90.7
 32000   34000        54      3.6      1415     94.3
 34000   36000        38      2.5      1453     96.9
 36000   38000        37      2.5      1490     99.3
 38000   40000         9      0.6      1499     99.9
 40000   42000         1      0.1      1500    100.0
TOTAL               1500    100.0
```



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STATISTIX FOR WINDOWS          August

FREQUENCY DISTRIBUTION OF SUMFLOW

                                        CUMULATIVE
   LOW    HIGH      FREQ  PERCENT      FREQ  PERCENT
 10000   12000         3      0.2         3      0.2
 12000   14000         3      0.2         6      0.4
 14000   16000         1      0.1         7      0.5
 16000   18000         1      0.1         8      0.5
 18000   20000         5      0.3        13      0.8
 20000   22000         3      0.2        16      1.0
 22000   24000        16      1.0        32      2.1
 24000   26000        24      1.5        56      3.6
 26000   28000        35      2.3        91      5.9
 28000   30000        82      5.3       173     11.2
 30000   32000        88      5.7       261     16.8
 32000   34000       113      7.3       374     24.1
 34000   36000        78      5.0       452     29.2
 36000   38000        90      5.8       542     35.0
 38000   40000        92      5.9       634     40.9
 40000   42000       112      7.2       746     48.1
 42000   44000       177     11.4       923     59.5
 44000   46000       145      9.4      1068     68.9
 46000   48000       122      7.9      1190     76.8
 48000   50000       105      6.8      1295     83.5
 50000   52000        69      4.5      1364     88.0
 52000   54000        49      3.2      1413     91.2
 54000   56000        34      2.2      1447     93.4
 56000   58000        38      2.5      1485     95.8
 58000   60000        23      1.5      1508     97.3
 60000   62000        34      2.2      1542     99.5
 62000   64000         6      0.4      1548     99.9
 64000   66000         2      0.1      1550    100.0
TOTAL               1550    100.0
```

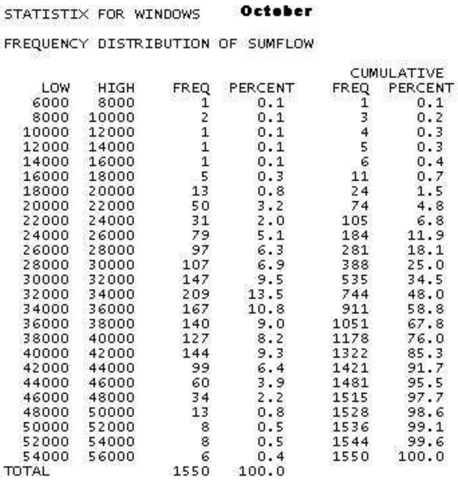

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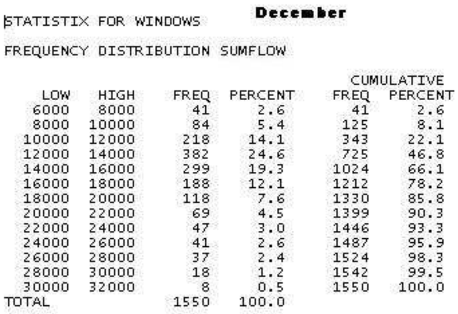
STATISTIX FOR WINDOWS          October

FREQUENCY DISTRIBUTION OF SUMFLOW

                                        CUMULATIVE
   LOW    HIGH      FREQ  PERCENT      FREQ  PERCENT
  6000    8000         1      0.1         1      0.1
  8000   10000         2      0.1         3      0.2
 10000   12000         1      0.1         4      0.3
 12000   14000         1      0.1         5      0.3
 14000   16000         1      0.1         6      0.4
 16000   18000         5      0.3        11      0.7
 18000   20000        13      0.8        24      1.5
 20000   22000        50      3.2        74      4.8
 22000   24000        31      2.0       105      6.8
 24000   26000        79      5.1       184     11.9
 26000   28000        97      6.3       281     18.1
 28000   30000       107      6.9       388     25.0
 30000   32000       147      9.5       535     34.5
 32000   34000       209     13.5       744     48.0
 34000   36000       167     10.8       911     58.8
 36000   38000       140      9.0      1051     67.8
 38000   40000       127      8.2      1178     76.0
 40000   42000       144      9.3      1322     85.3
 42000   44000        99      6.4      1421     91.7
 44000   46000        60      3.9      1481     95.5
 46000   48000        34      2.2      1515     97.7
 48000   50000        13      0.8      1528     98.6
 50000   52000         8      0.5      1536     99.1
 52000   54000         8      0.5      1544     99.6
 54000   56000         6      0.4      1550    100.0
TOTAL               1550    100.0
```



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STATISTIX FOR WINDOWS          December

FREQUENCY DISTRIBUTION SUMFLOW

                                        CUMULATIVE
   LOW    HIGH      FREQ  PERCENT      FREQ  PERCENT
  6000    8000        41      2.6        41      2.6
  8000   10000        84      5.4       125      8.1
 10000   12000       218     14.1       343     22.1
 12000   14000       382     24.6       725     46.8
 14000   16000       299     19.3      1024     66.1
 16000   18000       188     12.1      1212     78.2
 18000   20000       118      7.6      1330     85.8
 20000   22000        69      4.5      1399     90.3
 22000   24000        47      3.0      1446     93.3
 24000   26000        41      2.6      1487     95.9
 26000   28000        37      2.4      1524     98.3
 28000   30000        18      1.2      1542     99.5
 30000   32000         8      0.5      1550    100.0
TOTAL               1550    100.0
```