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TE RAUHĪTANGA TAIAO

Modelling Long-Term Daily Sediment Loads to the Mahurangi Estuary

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This report is part of a series of reports that were commissioned during the period 1993-1999 that were used to support the establishment of the Mahurangi Action Plan. They are being made available following a review of technical information.

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Modelling Long-Term Daily Sediment Loads to the Mahurangi Estuary

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1 Introduction

Since its commencement in 1994, biological monitoring of the Mahurangi Estuary has shown a loss of species diversity and a decline in the abundance and condition of horse mussels. Auckland Regional Council are unsure as to the cause of this decline in sediment sensitive species but suspect increased sedimentation and sediment flux within the Estuary. One possible cause for this increase is a change in rainfall patterns (increased rainfall) in recent years. In order to gain insight into the effect of rainfall patterns on sediment delivery to the estuary from the surrounding catchment Auckland Regional Council commissioned NIWA to use an established computer model to predict sediment yield over the long-term. By incorporating a constant land use within the model, any predicted changes in sediment flux can be attributed to climatic changes.

Stroud and Cooper (1997) describe the set up and validation of the BNZ (Basin – New Zealand) model for the Mahurangi catchment and model predictions of annual sediment load for the period 1976 - 1995. NIWA was asked by Auckland Regional Council to update these sediment predictions to the end of 2002.

Although the BNZ model operates on a daily time step, the original model was run in an "annual" output mode and so provided no information regarding the pattern of events producing the annual totals. Because both annual and event-based sediment loads can affect estuarine biota, we decided to adjust the model set up so simulations would output daily predictions of sediment delivered to the Estuary. This latest modelling study was conducted using a "daily" output mode for the period 1976 to 2002. This report provides information describing predictions of daily and annual sediment yields over this period.

2 Modelling

2.1 The Model

A full description of how the BNZ model works is given in Cooper and Bottcher (1993). Briefly, the catchment is divided into equal sized grid cells and user defined sub-catchments. Sediment generation for each cell is predicted using a modified version of the physically based field scale model CREAMS (Cooper et al 1992). CREAMS uses soils and land use data for each cell, together with long-term climate data (rainfall, temperature and radiation) to derive a daily water balance for each cell. Incoming rainfall is proportioned between surface runoff, storage in the soil profile, evapotranspiration and percolation beneath the root zone. The erosion component of CREAMS uses the daily predictions of surface runoff, coupled with soil properties, vegetation cover and topography, to predict daily sediment generation in each cell.

The sediment losses from each cell are spatially distributed by BNZ and routed down the drainage network, via sub-catchment outlets, to the catchment outlet. Stream channel attenuation is simulated during routing using stream reach length and predicted flow. Loadings from point sources can also be incorporated. The model works on a daily time step and assumes all sediment generated in a day will be delivered to the Estuary that same day.

2.2 Setting Up the BNZ Model

For the purposes of the modelling, the Mahurangi catchment was divided into 44 sub-catchments and 468 grid cells. Grid cell size was 500 m x 500 m. The total modelled area of the catchment is 117 km^2.

2.3 Model Input Information

The reader is referred to Stroud and Cooper (1997) for a detailed description and maps of the model input data. Some of the description is repeated here for convenience.

2.3.1 Soils

A soil map of the catchment was based on Landcare's 1:50,000 Land Resource Inventory database (as at 1995) and modified according to field studies commissioned by NIWA and carried out by Landcare. The main soil types of the area are derived from sedimentary rocks and are poorly draining, particularly through their subsoils.

2.3.2 Topography

Slope angles for the grid cells were obtained from a 1:50,000, 20-metre contour map. Slope angles were placed in one of six slope classes (as per the Land Resource Inventory) and the median value of each slope class was used as input to BNZ. Because of the coarse scale of this map, slope shape was assumed to be uniform. The majority of the catchment is rolling to strongly rolling land with flatter areas around the mainstem left and right branches of the Mahurangi River. There is a large area of steep land in the west of the catchment stretching from the estuary to Dark Summit and Moirs Hill. Most of the exotic forest in the catchment is located in this region. There is also some steeply sloping land in the northern tip near the Dome.

2.3.3 Land Use

Land use information for each cell in the model was obtained from a survey of landowners carried out by Auckland Regional Council (1995), a 1:10,000 aerial photograph of the region, vegetation cover given in the Land Resource Inventory, and a visit to the area to fill in any information gaps. The Mahurangi is predominantly a pastoral farming catchment with patches of native bush and scrub scattered throughout the region and a significant pine plantation belonging to Carter Holt Harvey in the west. There are a number of lifestyle blocks. Warkworth township is the main urban area.

2.3.4 Climate

Monthly mean air temperature data used in model runs were from the Warkworth Satellite Station (site A64463 (January 1976 - September 1999) and site A64464 (November 1999 – December 2002)). Monthly mean daily solar radiation data were from the Leigh Marine Laboratory (A64282) from January 1976 to October 1999 and from the Warkworth Satellite Station from when it started recording in November 1999 to December 2002. Gaps in the radiation and temperature data were filled with long-term mean values for that month.

From 1976 to 1995, daily rainfall totals were averaged from all the rainfall sites within the catchment (A64461, A64462, A64463) that had a record for each day. From 1996 to 2002 rainfall data was obtained from the Auckland Regional Council's Satellite site (644616). Annual totals of the daily rainfall data used in the modelling are listed in Table 1 and range between 1,222 and 2,473 mm per year.

On average, rainfall is reasonably well distributed through the year, although with somewhat higher monthly averages in winter (June — August). Temperature and radiation show expected seasonal patterns and may be expected to play a major role in determining hydrological pathways, with soil moisture deficits in summer due to high potential evapotranspiration (PET) and moisture excesses in winter.

2.4 Model Validation

Validation of the BNZ model was undertaken using flow and sediment data collected by Auckland Regional Council from 1 July 1994 to 30 June 1995 at three recording sites in the catchment; Redwood Forest, Wylies Road and Mahurangi College. The validation procedure and results are outlined in Stroud and Cooper (1997).

3 Model Results

The model was run from 1976 to 2002 (inclusive) in daily output mode, with data from the initial year (1976) being used to initialise the model and not included in reported model output. This gave over 9000 daily sediment load predictions for the existing land use for the 26-year period (1977-2002).

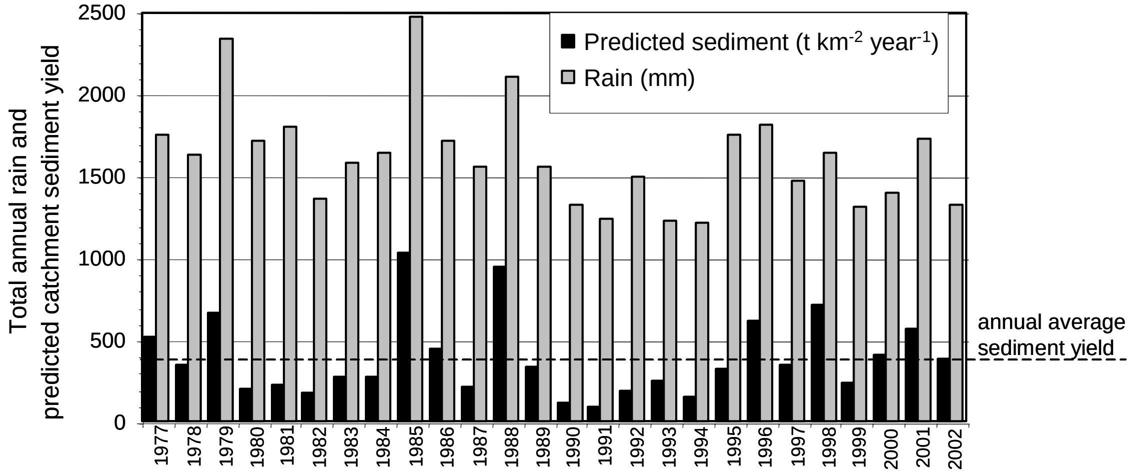
3.1 Annual Sediment Loads

Predicted annual sediment loads delivered to the Mahurangi Estuary from the surrounding catchment, and annual rainfall, for the years 1977 to 2002 are listed in Table 1 and plotted in Figure 1. The predicted annual sediment totals are a sum of the daily predictions for each year and differ slightly from the annual totals reported in Stroud and Cooper (1997) due to a difference between annual and daily modes in the method used to simulate in-stream attenuation.

Predicted annual average sediment load over the 26-year period is 45,852 tonnes (393 t km^{-2} $year^{-1}$). There is considerable year to year variation in the predicted annual sediment loads with the maximum load of 121,058 tonnes (1037 t km^{-2} $year^{-1}$) in 1985 being about eleven times greater than the minimum of 10,913 (93 t km^{-2} $year^{-1}$) in 1991. Figure 1 shows two extended periods with below annual average sediment load, 1980-1984 and 1989-1995. Depending on the nature and pattern of the observed decline in estuarine ecology, it may be helpful to broadly compare sediment loads before and after the start of the sampling period (mid 1994) Annual average sediment loads for the years prior to biological sampling (1977-1993) and post sampling (1994-2002) are 377 and 423 t km^{-2} $year^{-1}$, respectively.

Figure 1:

Predicted annual sediment load (t km-2 year-1) from the Mahurangi catchment and annual rainfall totals (mm).



3.2 Daily Sediment Loads

Predicted daily sediment loads for each year are plotted against time in Appendix 1. Average and maximum predictions of daily sediment are listed in Table 1 and plotted in Figures 2 and 3. The average daily sediment loads and daily maximum loads show a similar pattern to the total annual loads with periods of low average and maximum delivery from 1980 to 1982 and 1990 to 1992. The years with the highest predicted average daily sediment load were 1985 and 1988 and the two lowest were 1991 and 1992. The two largest sediment events occurred in 1985 and 1988. The two smallest events occurred in 1981 and 1991.

Table 1:

Summary of annual and daily BNZ predicted sediment loads from the Mahurangi catchment and annual totals of the rainfall used in the modelling.

	Total annual sediment (tonnes year^{-1})	Total annual rainfall (mm)	Mean daily sediment (tonnes day^{-1})	Maximum daily sediment (tonnes day^{-1})
1977	61439	1761	168	15653
1978	41722	1634	114	15335
1979	77926	2342	213	10168
1980	24834	1715	68	7637
1981	26761	1802	73	4737
1982	20703	1366	57	5861
1983	33388	1588	91	10234
1984	32896	1642	90	8549
1985	121058	2473	332	42288
1986	52990	1720	145	11527
1987	25921	1565	71	7707
1988	110440	2116	302	38145
1989	39604	1565	109	11533
1990	14686	1334	40	5385
1991	10913	1250	30	3776
1992	22337	1503	61	5277
1993	30299	1230	83	12831
1994	18099	1222	50	9311
1995	38895	1761	107	19402
1996	72498	1815	198	17911
1997	41503	1477	114	7332
1998	84034	1645	230	29993
1999	27910	1314	76	10570
2000	48441	1407	132	14677
2001	67061	1736	184	33460
2002	45785	1328	125	27329

Figure 2:

Model predicted mean daily sediment load (tonnes day^{-1}) from the Mahurangi catchment.

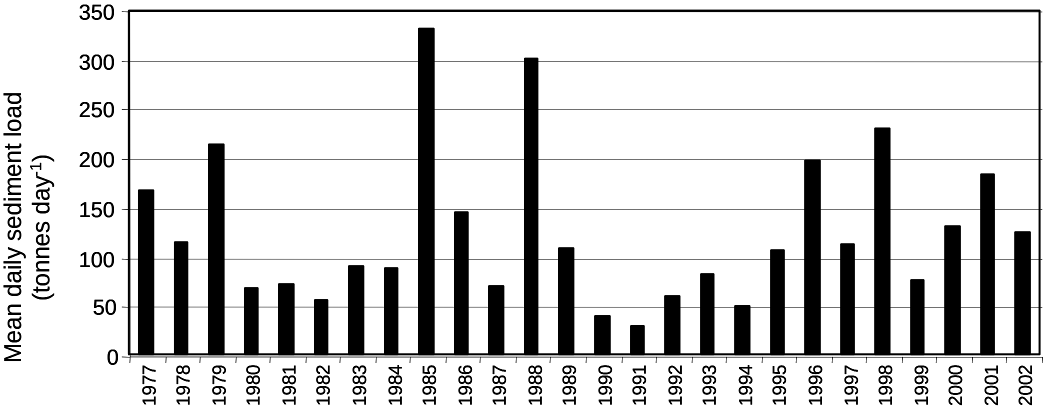
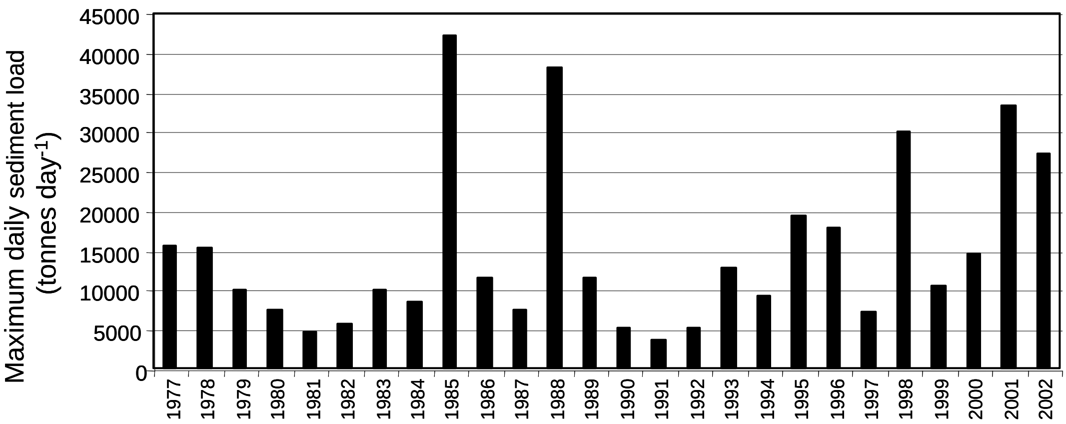


Figure 3:

Model predicted maximum daily sediment load (tonnes day-1) from the Mahurangi catchment.



Sediment delivered to an estuary can affect estuarine ecology in a variety of ways depending on the quantity and nature of sediment, its frequency of arrival, the hydrodynamics in the estuary at the time of delivery (which determines the fate of the sediment) and the life cycle stages of biological species present at the time of delivery (which affects their sensitivity to sediment). Large infrequent events may cause direct smothering of biota (acute effects) and smaller more frequent events may result in increased sediment presence in the water column (sub-lethal effects). It would be helpful to use the daily model predictions of sediment load to assess whether climatic conditions may have changed the pattern of sediment events in the Mahurangi. We have taken three approaches to this; 1.) Determining what proportion the three largest daily loads in each year contribute to the total annual load for that year; 2.) Quantifying the number of days in each year predicted daily loads fall within certain value ranges; 3.) Calculating the return period of each predicted daily load for the 26-year period.

Because the model assumes there is no time delay between generation of sediment on the hill slope and delivery to the estuary there are numerous days predicted to have no sediment load. For this reason we used daily loads rather than summing loads over an event and also for this reason, predicted daily loads are best used on a comparative rather than absolute basis.

Figure 4 illustrates how much the three largest daily sediment loads of each year contribute to the total load for that year. The contribution of maximum daily load ranges from 13% to 60% of the total annual load. The contribution of the three largest daily sediment loads combined ranges from 35% to 89%. 1985 and 1988 have the highest annual sediment yield. For both these years the modelling predicts 35% of the yield is delivered in one event and approximately 50% over three events.

Figure 4 also shows the large inter-annual variation in sediment load, with some years having a maximum daily load greater than some total annual loads.

Figure 4:

The three largest predicted daily sediment loads as a proportion of total predicted annual load.

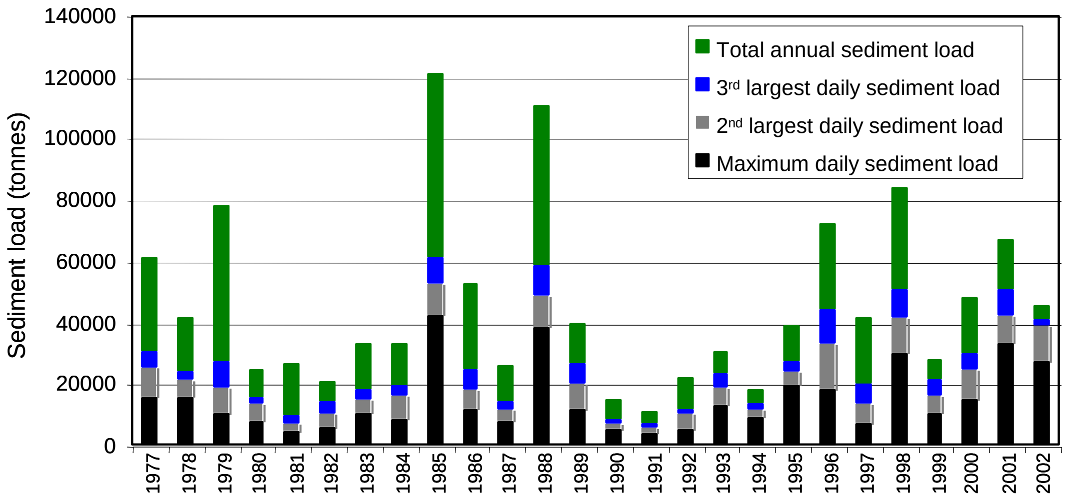


Table 2 expands on Figure 4 in that it shows the number of days in each year the daily sediment load falls into a range of categories. It illustrates how the distribution of annual sediment load among different sized events can vary from year to year. For example, 1981 has a total predicted annual sediment load of 26,761 tonnes with all daily loads less than 5,000 tonnes year^{-1}. Compare this to 1999 which has a similar predicted annual sediment load (27,910 tonnes year^{-1}) but has one daily load greater than 10,000 tonnes and two daily loads greater than 5,000 tonnes. In general the years with the highest annual sediment loads also have the greatest number of days with a predicted daily load greater than 5,000 tonnes.

Table 2 also lists the average number of days per year the predicted daily sediment load falls into each category. The averages are given for the complete time period (1977-2002) and for both pre- (1977-1993) and post- (1994-2002) biological sampling.

The pre-sampling period is predicted to have a greater average number of days with sediment loads less than 5,000 tonnes day^{-1} than the post-sampling period. However the post-sampling period has a greater average number of days with sediment loads between 5,000 and 30,000 tonnes day^{-1}. Both periods have the same average number of days with a load greater than 30,000 tonnes day^{-1}.

The return period analysis is similar to that of the distribution table except the categories are based on return period of the daily load rather than the load size. Return periods were calculated for predicted daily sediment loads using the equation $T = n/m$, where T is the return period in years, n is the number of years of record (26) and m is the rank of the event (Chow et al., 1988). We have not extrapolated the data past the 26 years of climate record so the maximum return period calculated is the length of climate record i.e., 26 years.

Figure 5 shows the number of days per year with a sediment load return period greater than or equal to 0.25, 0.5, 1 and 1.5 years. The daily sediment load corresponding to these return periods is approximately 3,000, 6,000 9,500 and 11,000 tonnes respectively. Figures 5B and 5C illustrate a lack of large events during the periods 1980 to 1982 and 1990 to 1992. Figure 5D highlights 1996 as the year the most events with a return period of 1.5 years or more even though it does not have a particularly high maximum load (Figure 3).

The average number of days per year with a sediment load greater than 0.25, 0.5, 1 and 1.5 years is 3.9, 1.8, 0.8, and 0.4 respectively, for the pre-sampling period and 4.4, 2.4, 1.3 and 1 respectively, for the post-sampling period.

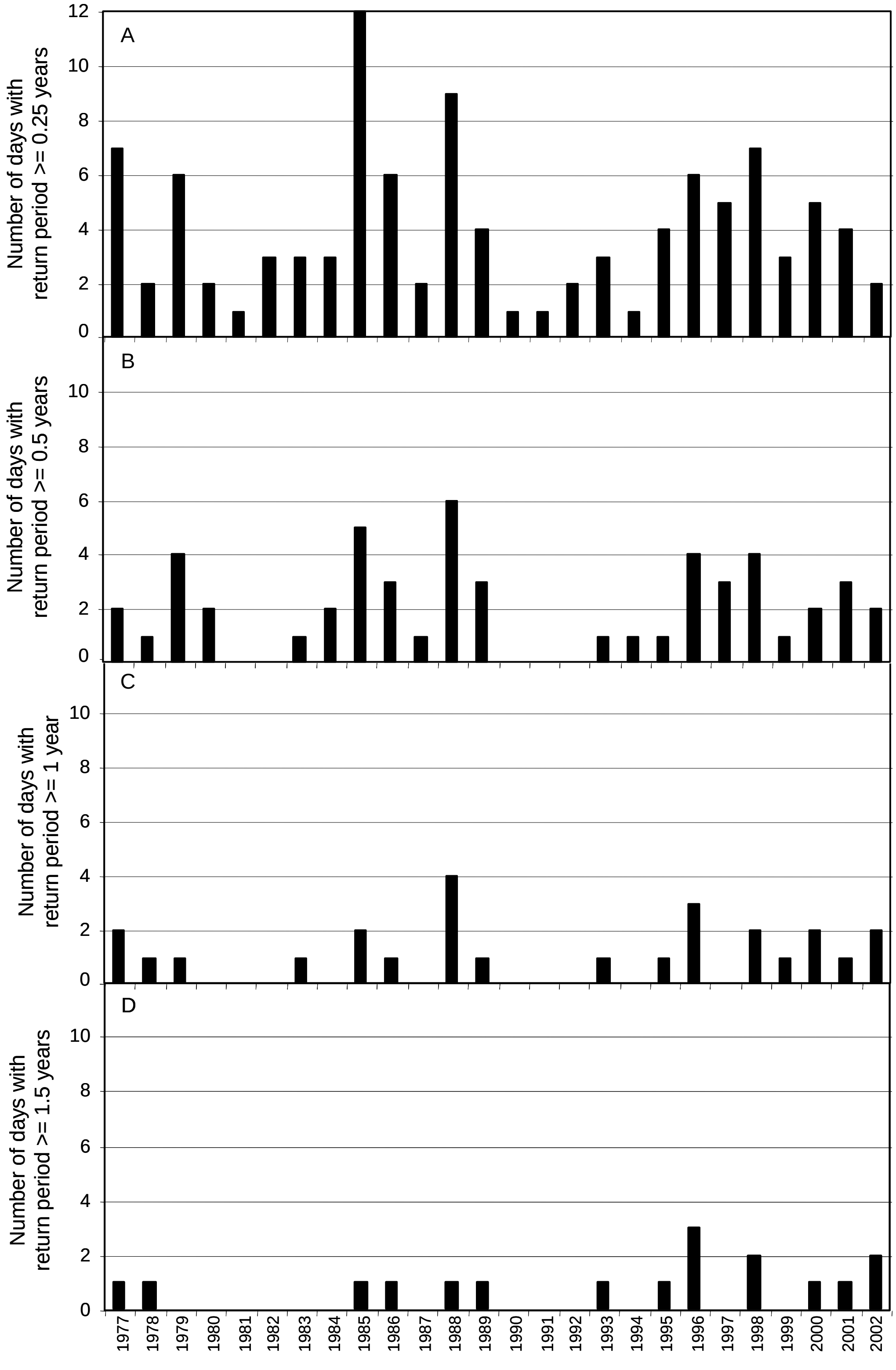
Table 2:

The number of days in each year and the average number of days per year, the daily sediment load falls into 10 different value ranges (tonnes day-1).

	Number of days within each range of predicted daily sediment loads									
Tonnes day^{-1}	<1	1-10	10-50	50-100	100 -500	500 -1000	1000-5000	5000-10000	10000-30000	>30000
Year										
1977	316	5	12	5	11	3	10	2	1	0
1978	312	8	13	3	17	2	8	1	1	0
1979	292	7	14	6	22	4	15	4	1	0
1980	316	8	17	6	9	6	2	2	0	0
1981	299	10	18	5	16	10	7	0	0	0
1982	332	4	9	1	12	3	3	1	0	0
1983	321	7	9	4	10	8	5	0	1	0
1984	323	7	10	4	9	6	5	2	0	0
1985	300	7	17	7	11	4	14	3	1	1
1986	317	4	11	4	13	3	10	2	1	0
1987	326	4	10	4	10	4	6	1	0	0
1988	307	12	12	2	15	6	6	4	1	1
1989	318	9	14	3	12	2	4	2	1	0
1990	318	8	13	8	12	2	3	1	0	0
1991	329	10	15	2	4	1	4	0	0	0
1992	316	6	9	4	19	9	1	2	0	0
1993	338	7	4	4	4	3	3	1	1	0
1994	333	3	7	3	15	1	2	1	0	0
1995	321	7	13	7	8	3	5	0	1	0
1996	315	7	11	6	17	4	0	3	3	0
1997	326	6	9	3	10	3	4	4	0	0
1998	334	1	3	3	10	5	3	4	2	0
1999	334	4	10	5	6	1	2	2	1	0
2000	340	2	7	3	3	1	8	0	2	0
2001	333	4	5	3	9	4	4	2	0	1
2002	329	11	9	1	9	2	2	0	2	0
Mean 1977-2002	321.0	6.5	10.8	4.1	11.3	3.8	5.2	1.7	0.8	0.1
Mean 1977-1993	316.5	7.2	12.2	4.2	12.1	4.5	6.2	1.6	0.5	0.1
Mean 1994-2002	329.4	5.0	8.2	3.8	9.7	2.7	3.3	1.8	1.2	0.1

Figure 5:

The number of days per year with a sediment load return period greater than or equal to 0.25 (A), 0.5 (B), 1 (C) and 1.5 (D) years.



4 Conclusion

Long-term modelling of sediment load delivered to the Mahurangi Estuary predicts large year-to-year variation in total annual loads with periods of lower than average annual load from 1980-1984 and 1989-1995. The predicted annual average load for the years since biological sampling began (1994-2002) is higher than the years prior to sampling (1977-1993).

From an analysis of the daily data, the modelling also predicts the pattern of event loads to vary from year to year, even for years with a similar annual load. In general however, those years with the highest predicted annual loads also have the greatest predicted number of days with high daily loads. Predicted mean daily loads for each year show a similar pattern to total annual loads and the modelling predicts a lack of large events from 1980 to 1982 and 1990 to 1992.

The modelling also predicts a higher average number of small events per year and a lower average number of large events per year for the pre-biological sampling period compared to the post-sampling period.

It is not clear, however, whether this pattern can explain the observed loss in species diversity. To address this question requires the coupling of predictions of sedimentation within the estuary (as distinct from catchment sediment yields simulated in this study, which feed into a sedimentation model) with an understanding of the response of each species to sedimentation events.

5 References

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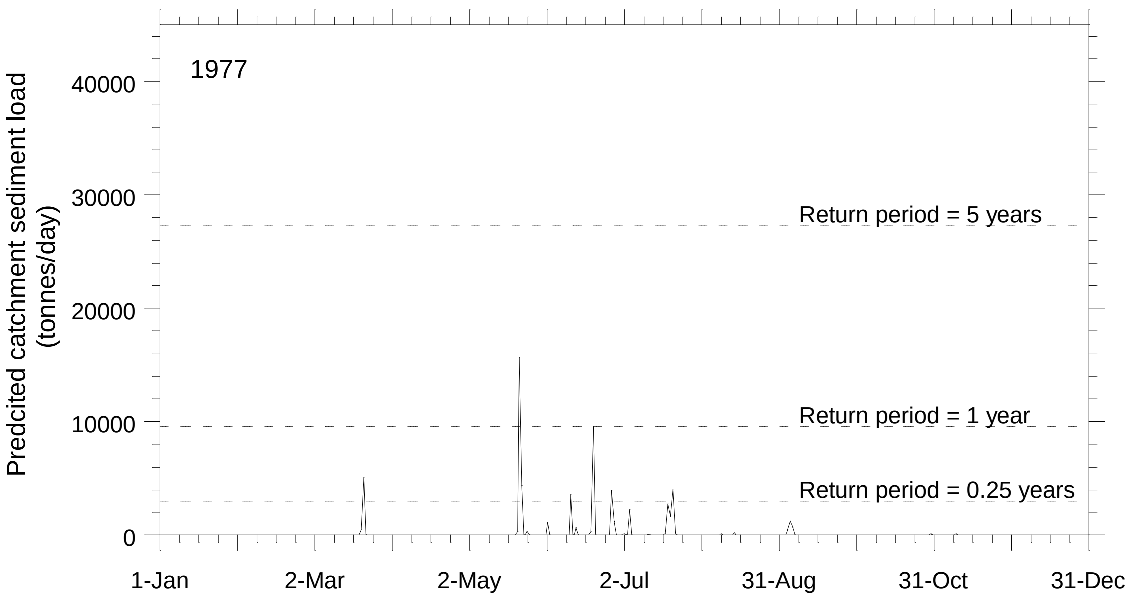
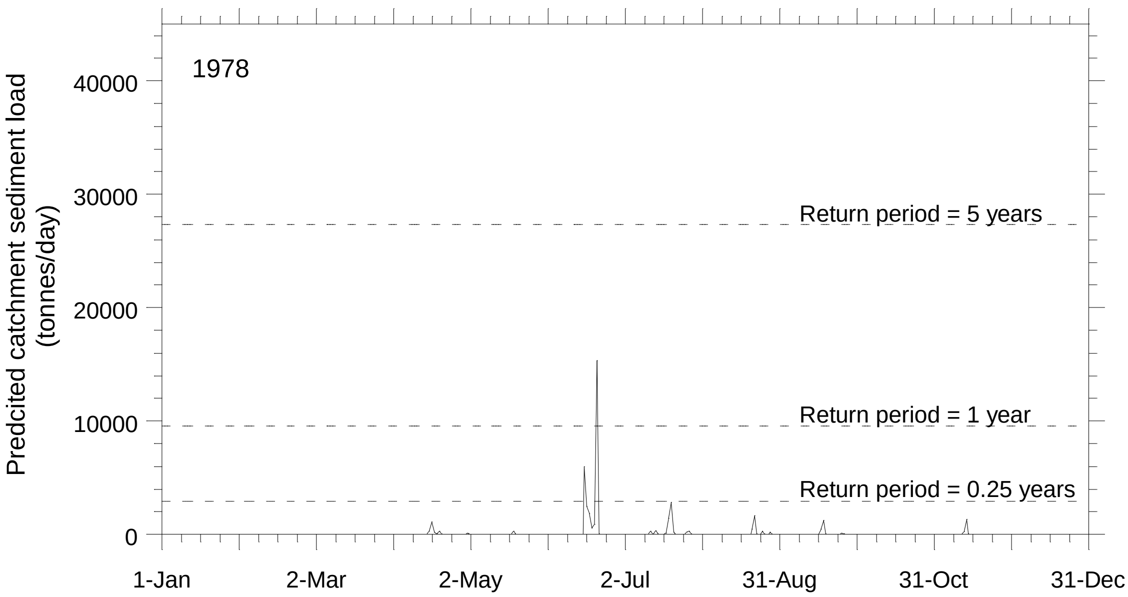
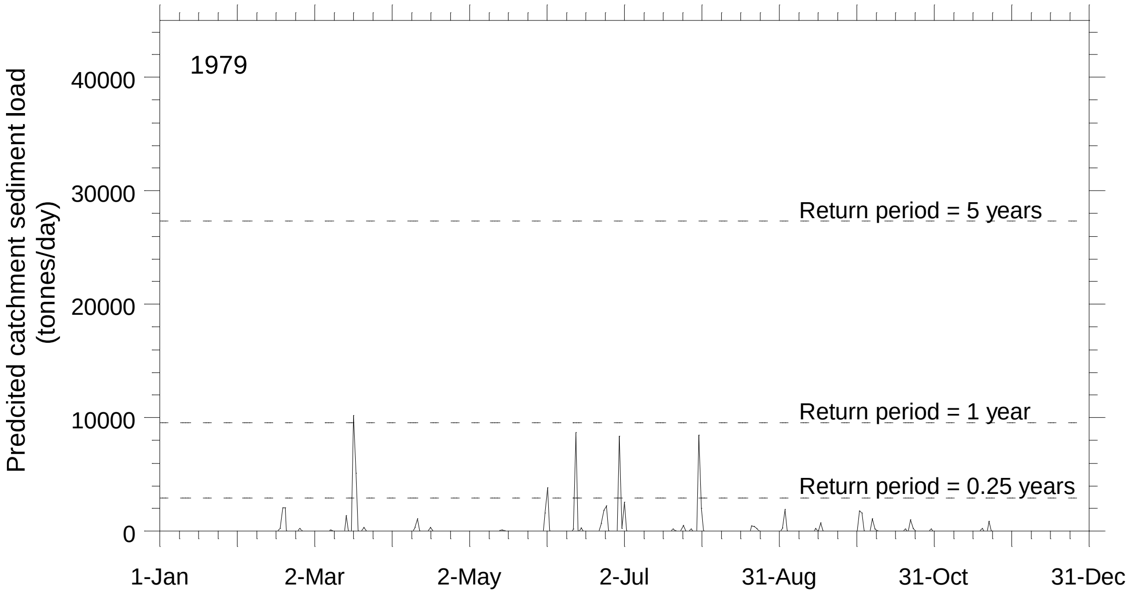
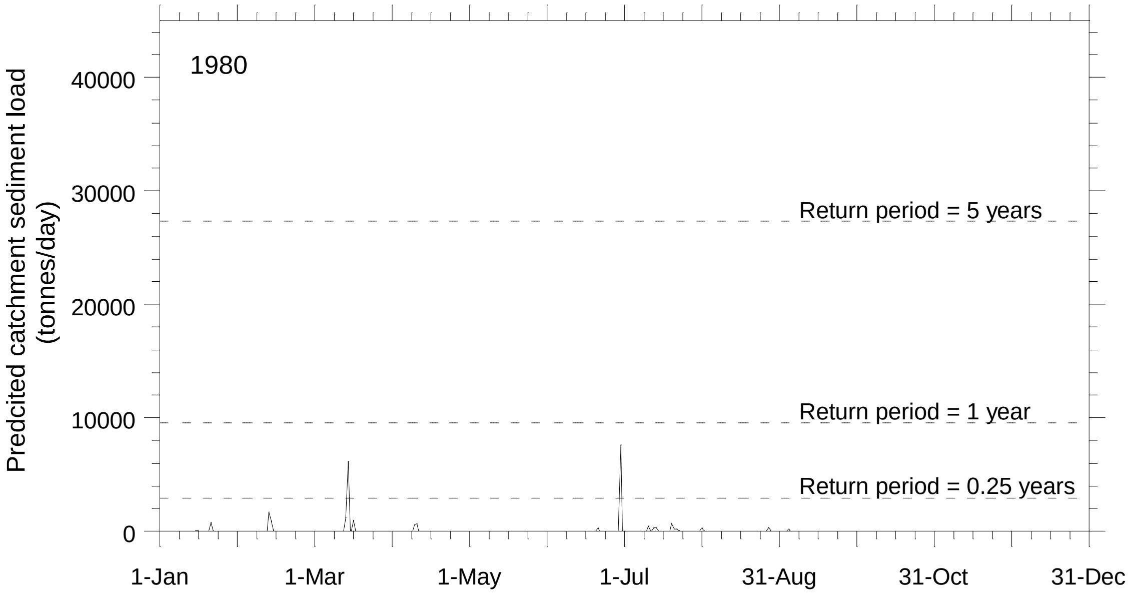
Appendix 1

Predicted daily sediment loads for plotted against time for each year of the modelling study (1977-2002).






1979
Predcited catchment sediment load (tonnes/day)
40000
30000
20000
10000
0
Return period = 5 years
Return period = 1 year
Return period = 0.25 years
1-Jan
2-Mar
2-May
2-Jul
31-Aug
31-Oct
31-Dec


1980
Predcited catchment sediment load (tonnes/day)
40000
30000
20000
10000
0
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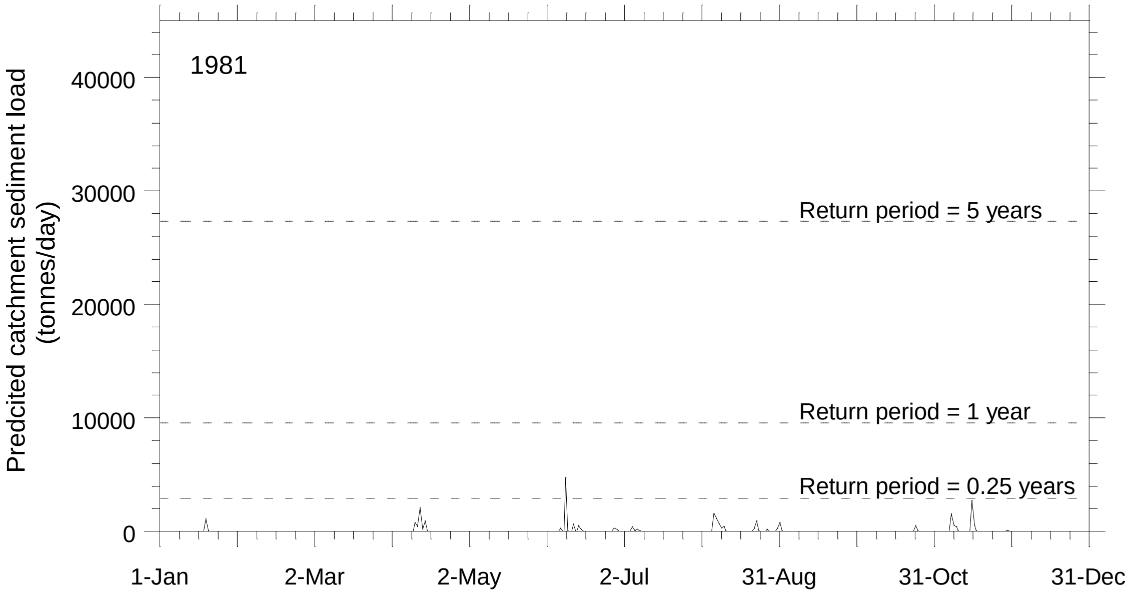
Return period = 1 year
Return period = 0.25 years
1-Jan
1-Mar
1-May
1-Jul
31-Aug
31-Oct
31-Dec


1981
Predcited catchment sediment load (tonnes/day)
40000
30000
20000
10000
0
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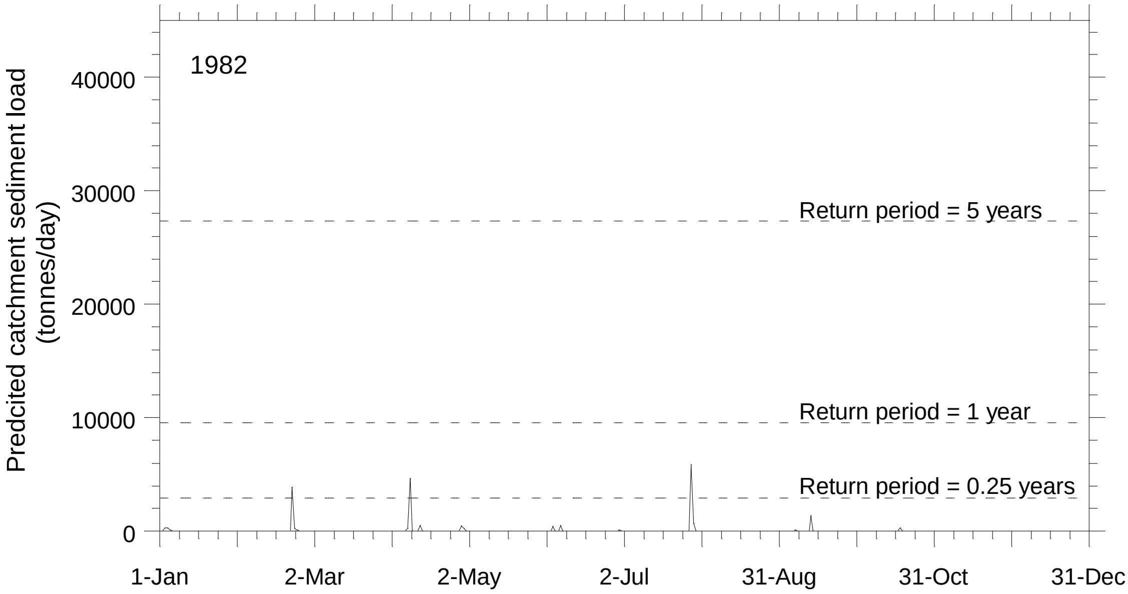
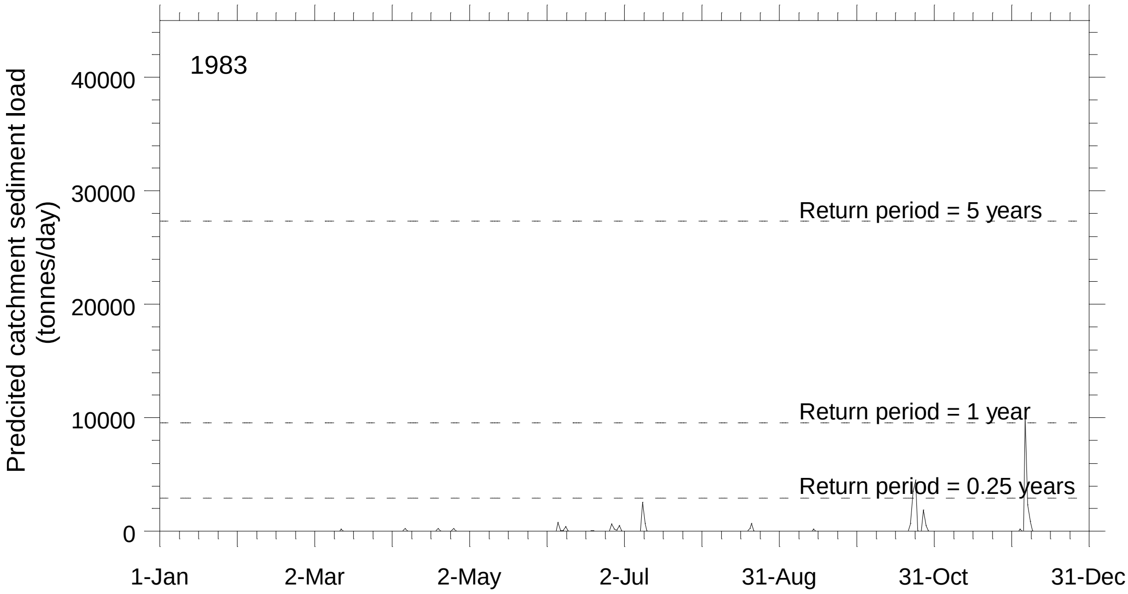
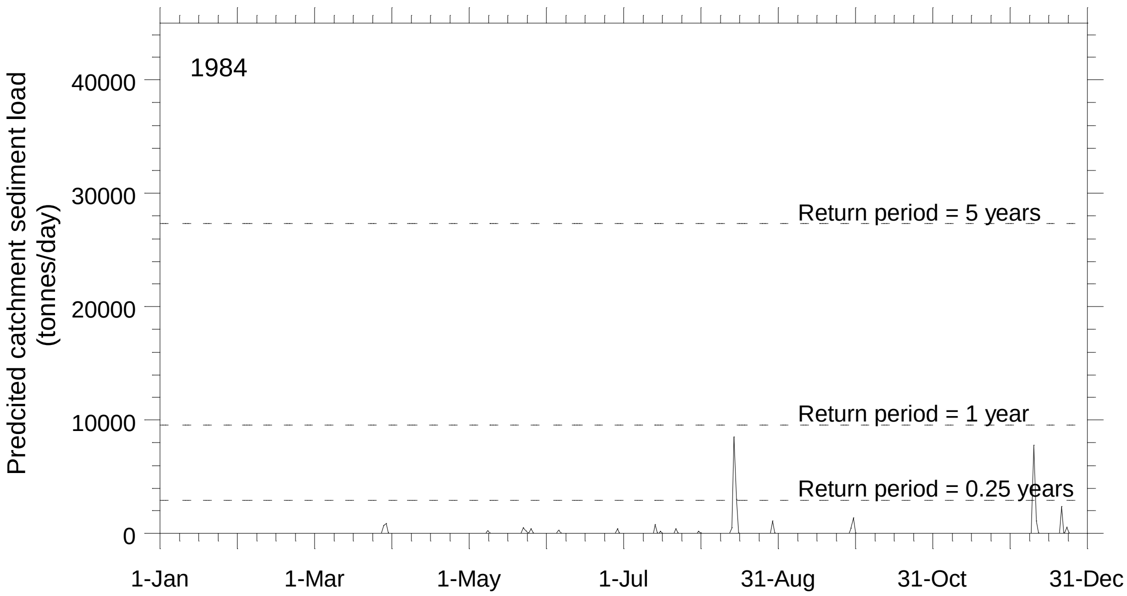
Return period = 1 year
Return period = 0.25 years
1-Jan
2-Mar
2-May
2-Jul
31-Aug
31-Oct
31-Dec


1982
Predcited catchment sediment load (tonnes/day)
40000
30000
20000
10000
0
Return period = 5 years
Return period = 1 year
Return period = 0.25 years
1-Jan
2-Mar
2-May
2-Jul
31-Aug
31-Oct
31-Dec


1983
Predcited catchment sediment load (tonnes/day)
40000
30000
20000
10000
0
Return period = 5 years
Return period = 1 year
Return period = 0.25 years
1-Jan
2-Mar
2-May
2-Jul
31-Aug
31-Oct
31-Dec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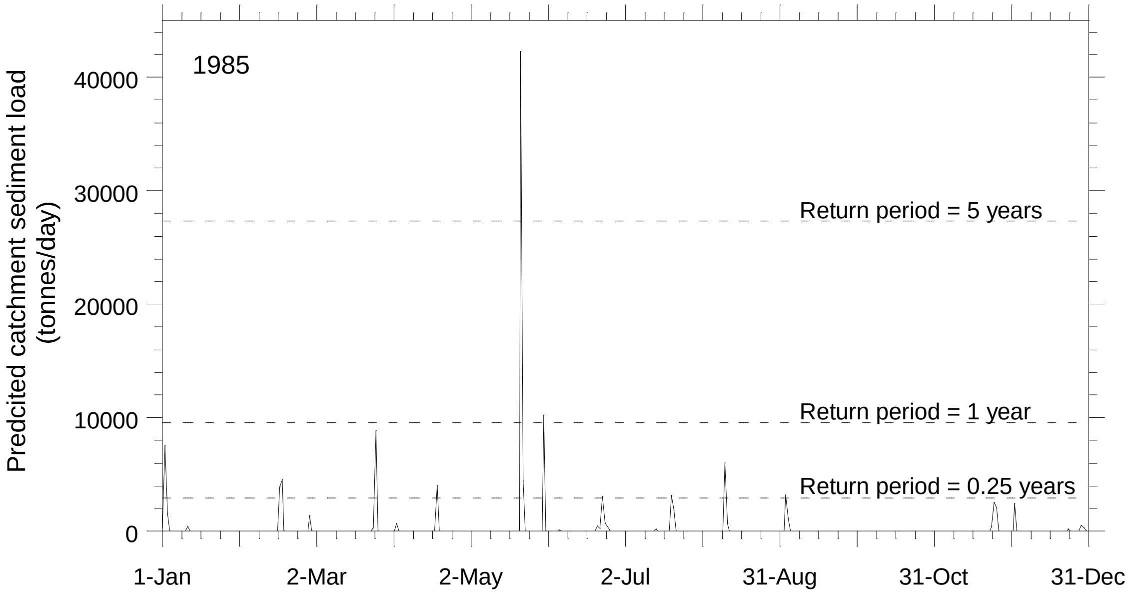
Predcited catchment sediment load (tonnes/day)
40000
30000
20000
10000
0
Return period = 5 years
Return period = 1 year
Return period = 0.25 years
1-Jan
1-Mar
1-May
1-Jul
31-Aug
31-Oct
31-Dec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Predcited catchment sediment load (tonnes/day)
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20000
10000
0
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Return period = 1 year
Return period = 0.25 years
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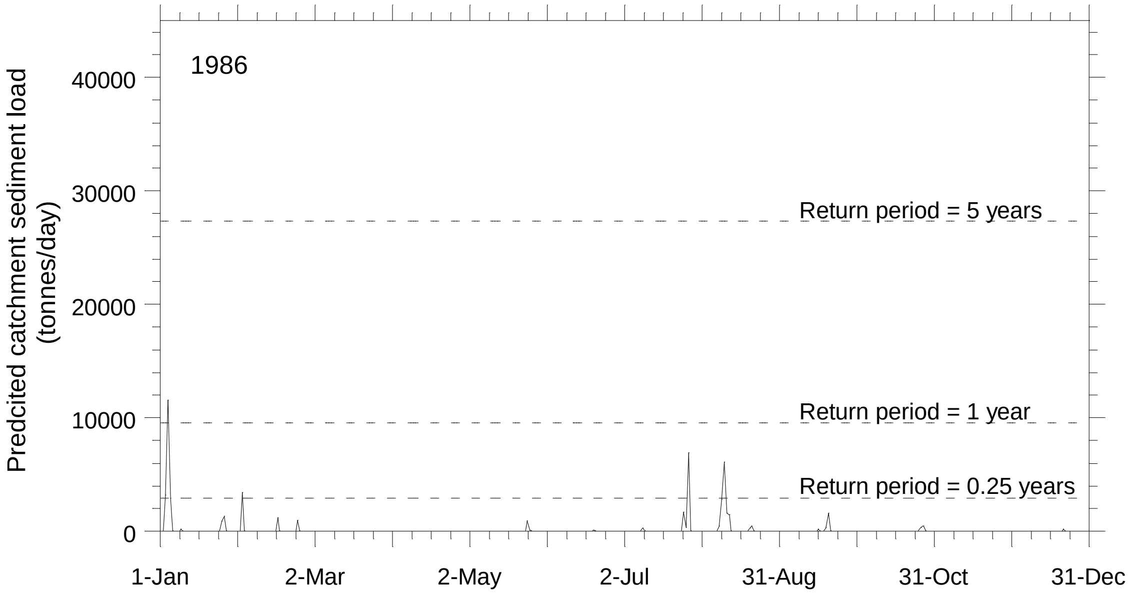
2-Mar
2-May
2-Jul
31-Aug
31-Oct
31-Dec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Predcited catchment sediment load (tonnes/day)
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20000
10000
0
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Return period = 1 year
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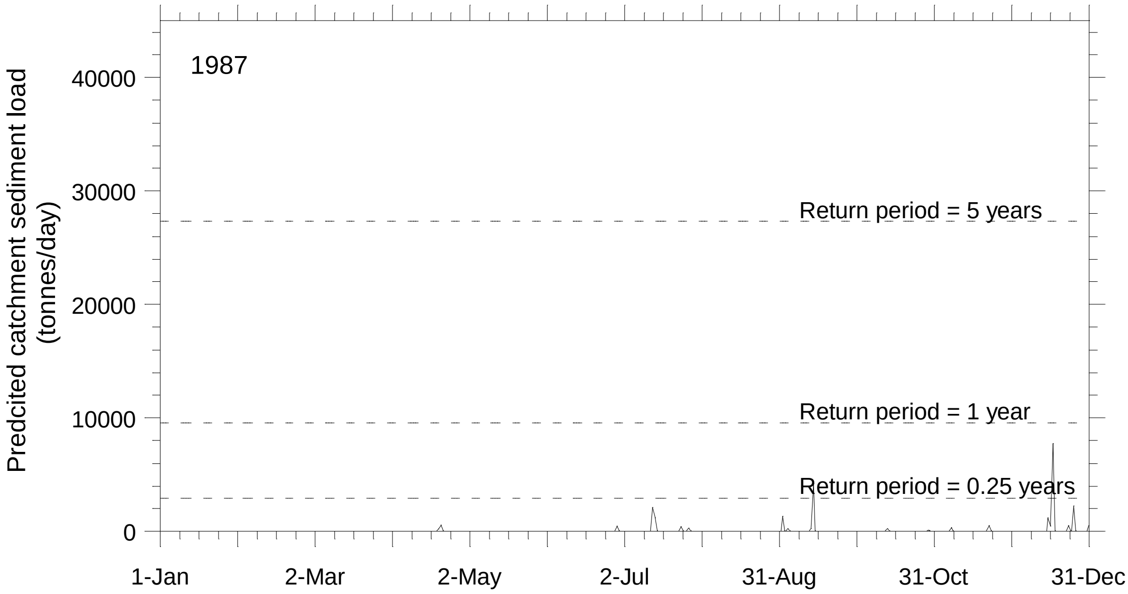
2-May
2-Jul
31-Aug
31-Oct
31-Dec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Predcited catchment sediment load (tonnes/day)
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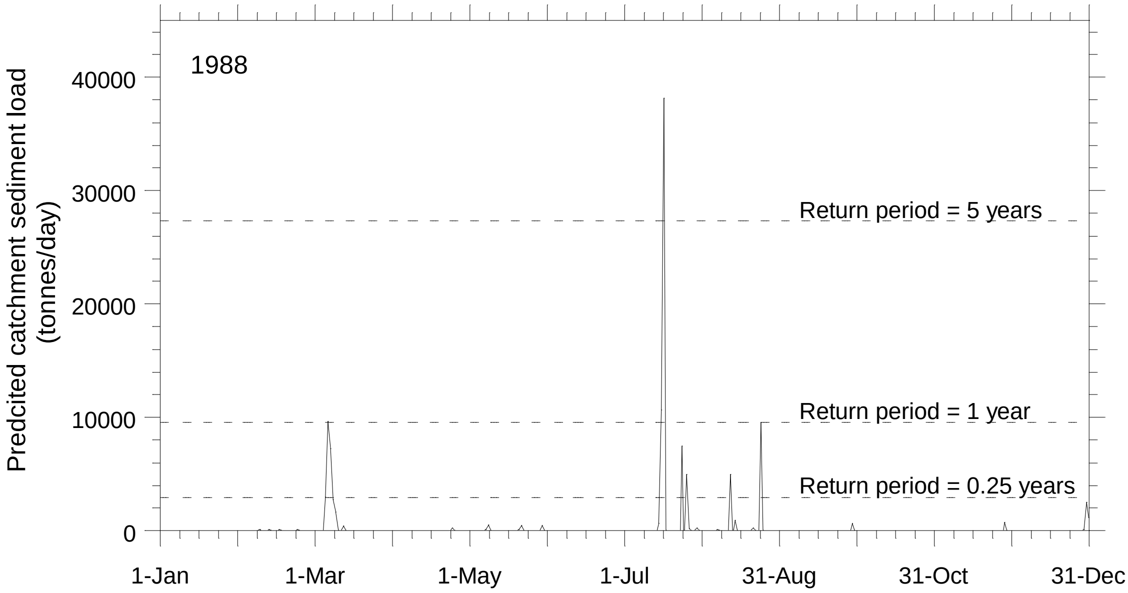
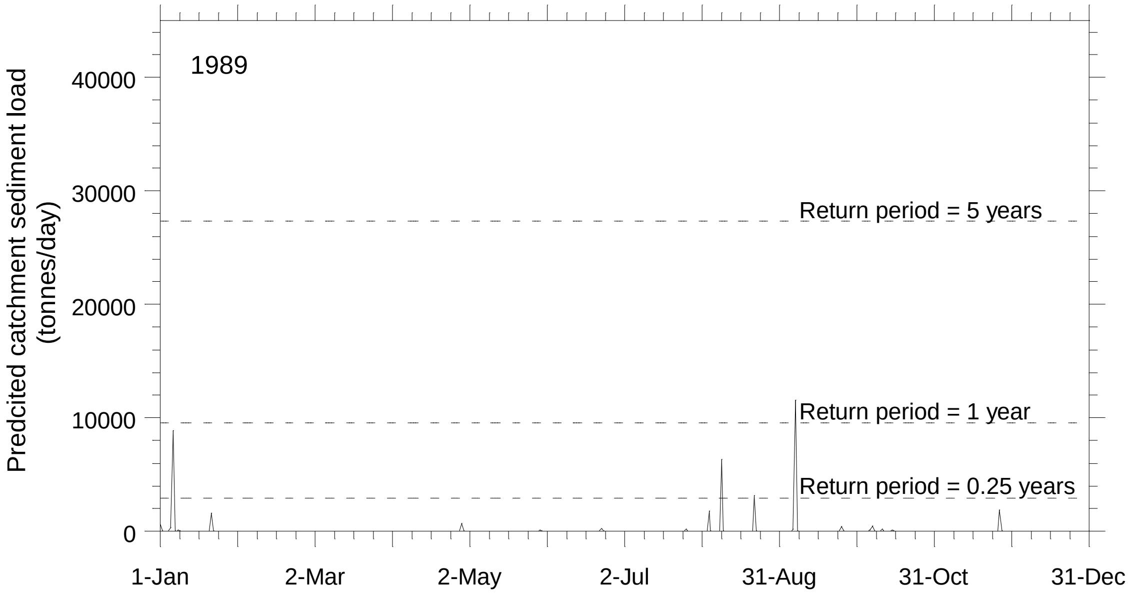
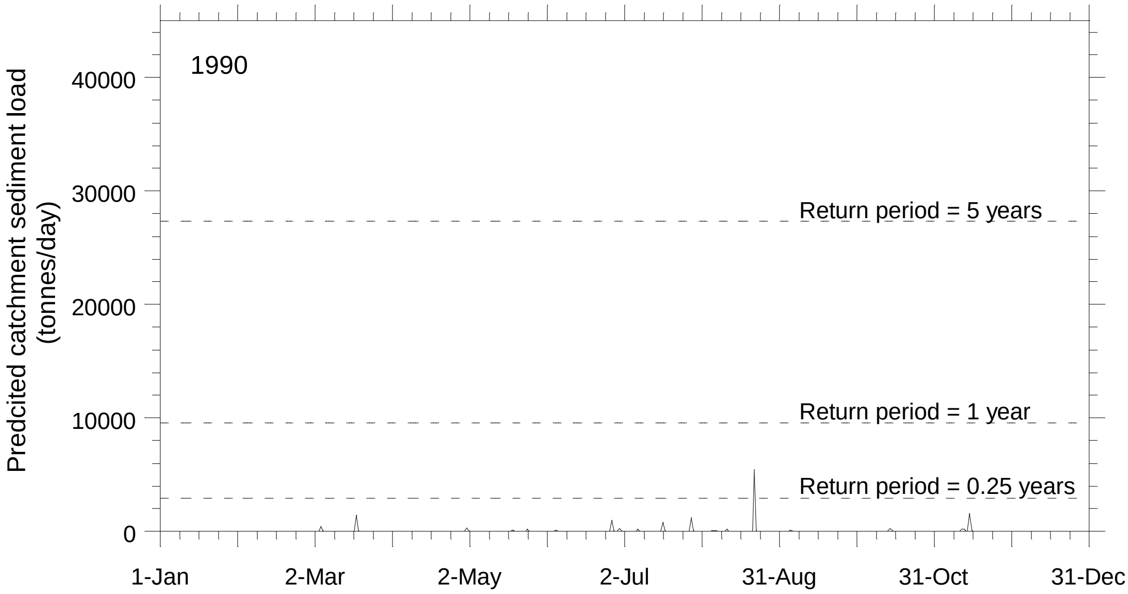
30000
20000
10000
0
Return period = 5 years
Return period = 1 year
Return period = 0.25 years
1-Jan
2-Mar
2-May
2-Jul
31-Aug
31-Oct
31-Dec


1988
Predcited catchment sediment load (tonnes/day)
40000
30000
20000
10000
0
Return period = 5 years
Return period = 1 year
Return period = 0.25 years
1-Jan
1-Mar
1-May
1-Jul
31-Aug
31-Oct
31-Dec


1989
Predcited catchment sediment load (tonnes/day)
40000
30000
20000
10000
0
Return period = 5 years
Return period = 1 year
Return period = 0.25 years
1-Jan
2-Mar
2-May
2-Jul
31-Aug
31-Oct
31-Dec


1990
Predcited catchment sediment load (tonnes/day)
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30000
20000
10000
0
Return period = 5 years
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Return period = 0.25 years
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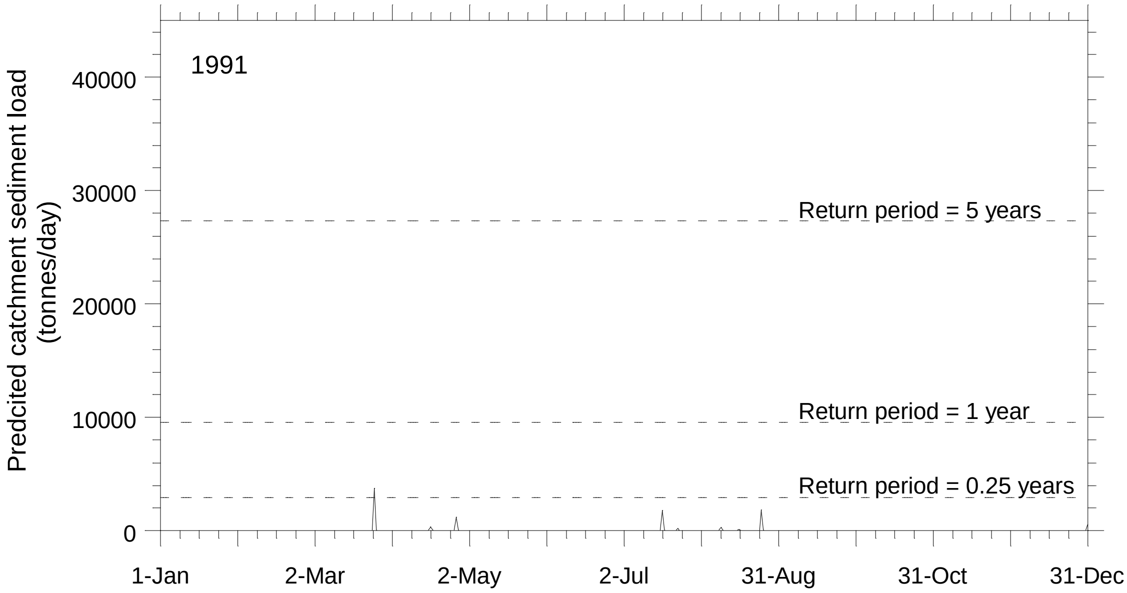
2-Mar
2-May
2-Jul
31-Aug
31-Oct
31-Dec


1991
Predcited catchment sediment load (tonnes/day)
40000
30000
20000
10000
0
Return period = 5 years
Return period = 1 year
Return period = 0.25 years
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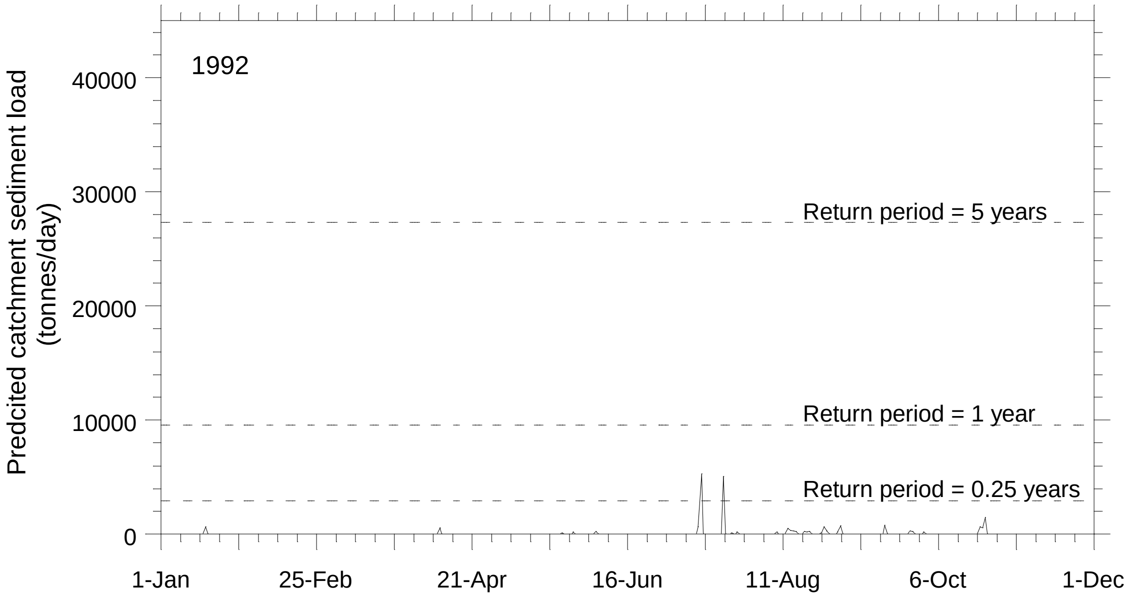
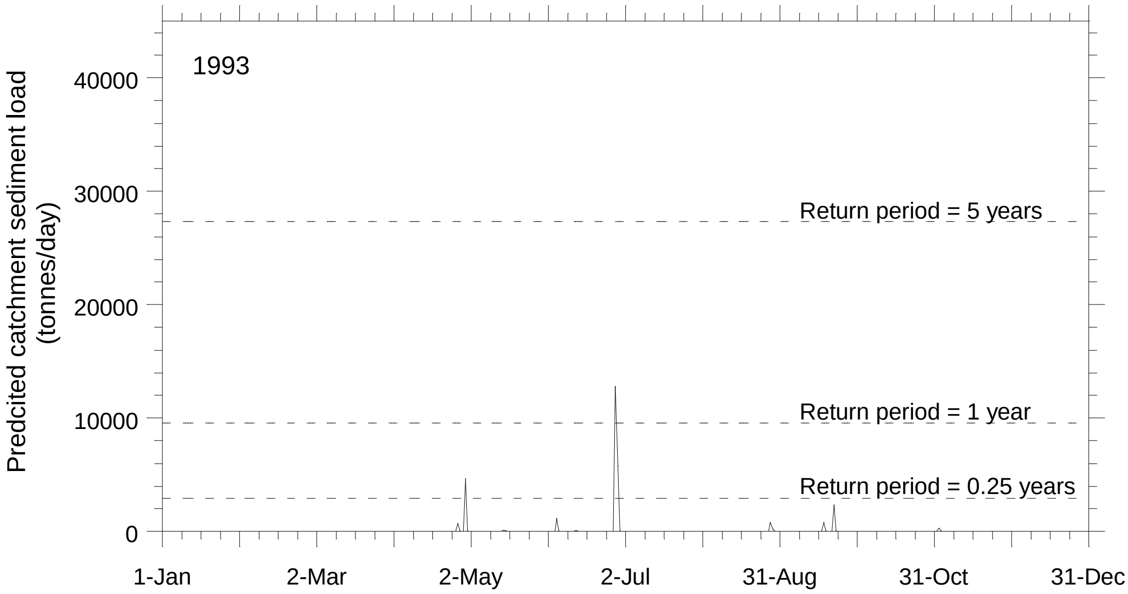
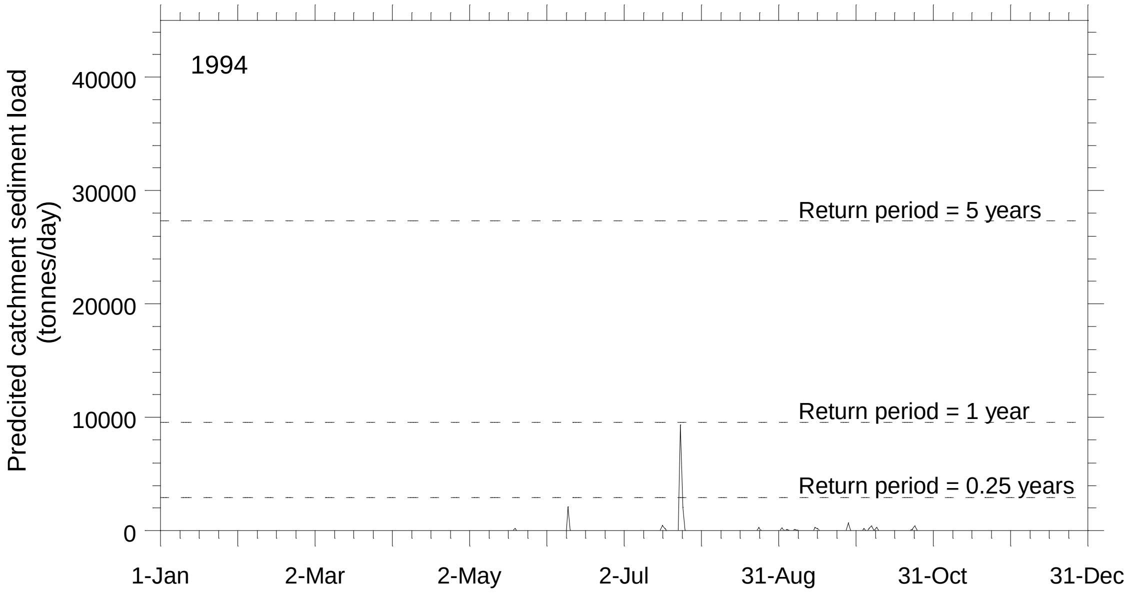
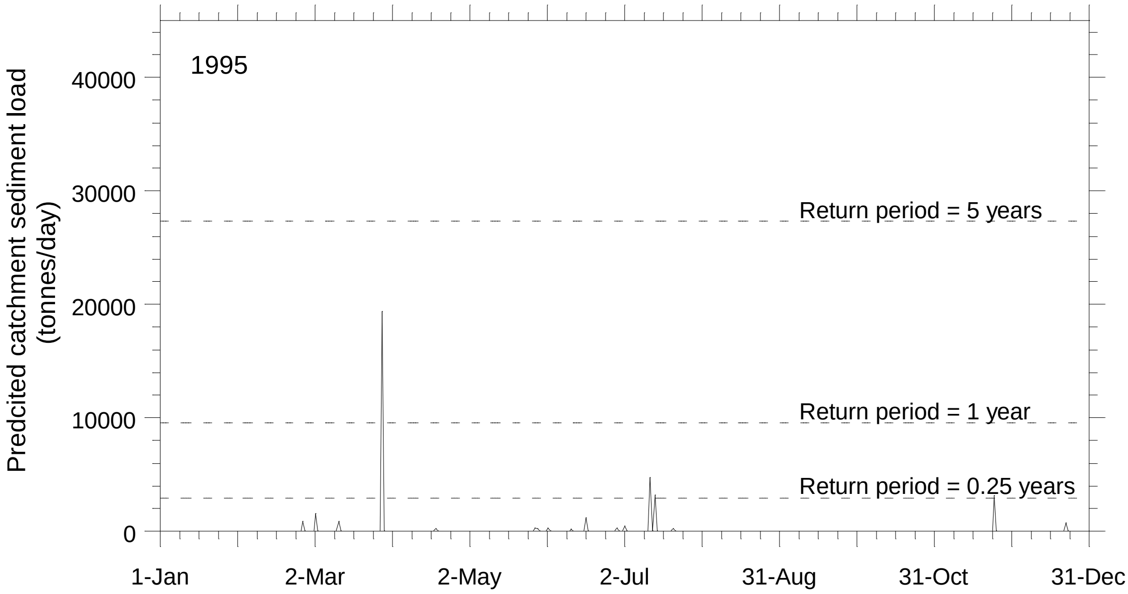
2-Mar
2-May
2-Jul
31-Aug
31-Oct
31-Dec


1992
Predcited catchment sediment load (tonnes/day)
40000
30000
20000
10000
0
Return period = 5 years
Return period = 1 year
Return period = 0.25 years
1-Jan
25-Feb
21-Apr
16-Jun
11-Aug
6-Oct
1-Dec


1993
Predcited catchment sediment load (tonnes/day)
40000
30000
20000
10000
0
Return period = 5 years
Return period = 1 year
Return period = 0.25 years
1-Jan
2-Mar
2-May
2-Jul
31-Aug
31-Oct
31-Dec


1994
Predcited catchment sediment load (tonnes/day)
40000
30000
20000
10000
0
Return period = 5 years
Return period = 1 year
Return period = 0.25 years
1-Jan
2-Mar
2-May
2-Jul
31-Aug
31-Oct
31-Dec


1995
Predcited catchment sediment load (tonnes/day)
40000
30000
20000
10000
0
Return period = 5 years
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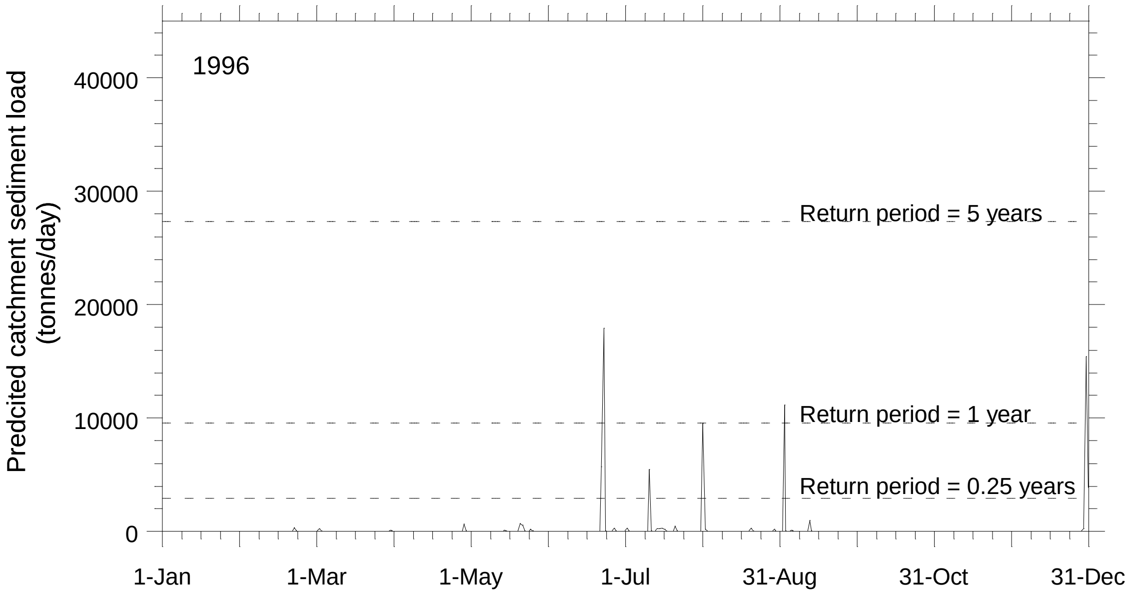
Return period = 0.25 years
1-Jan
2-Mar
2-May
2-Jul
31-Aug
31-Oct
31-Dec


1996
Predicted catchment sediment load (tonnes/day)
40000
30000
20000
10000
0
Return period = 5 years
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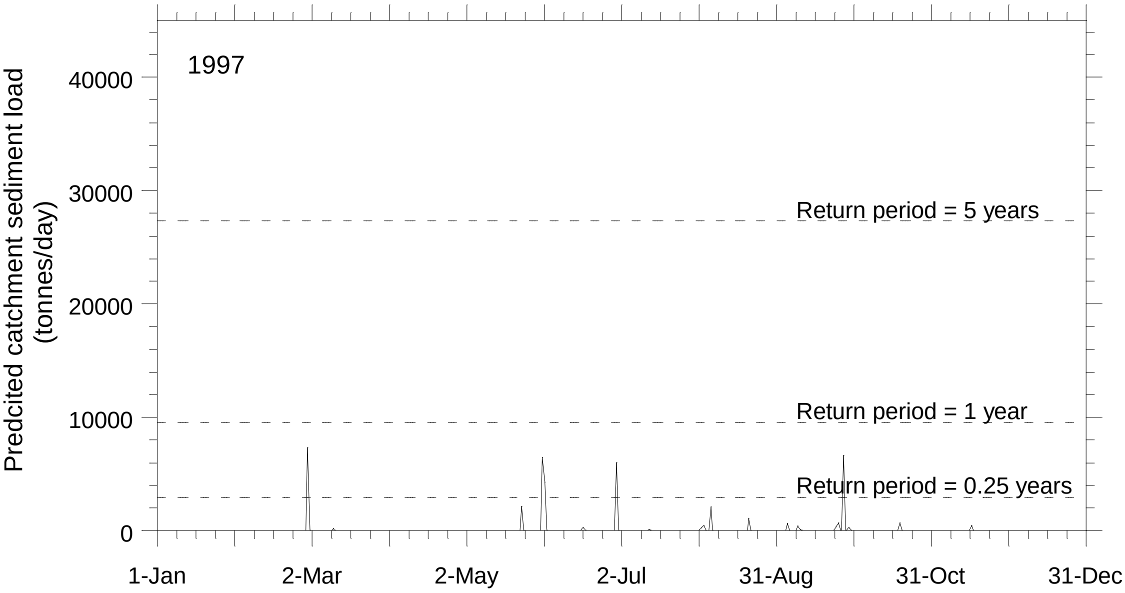
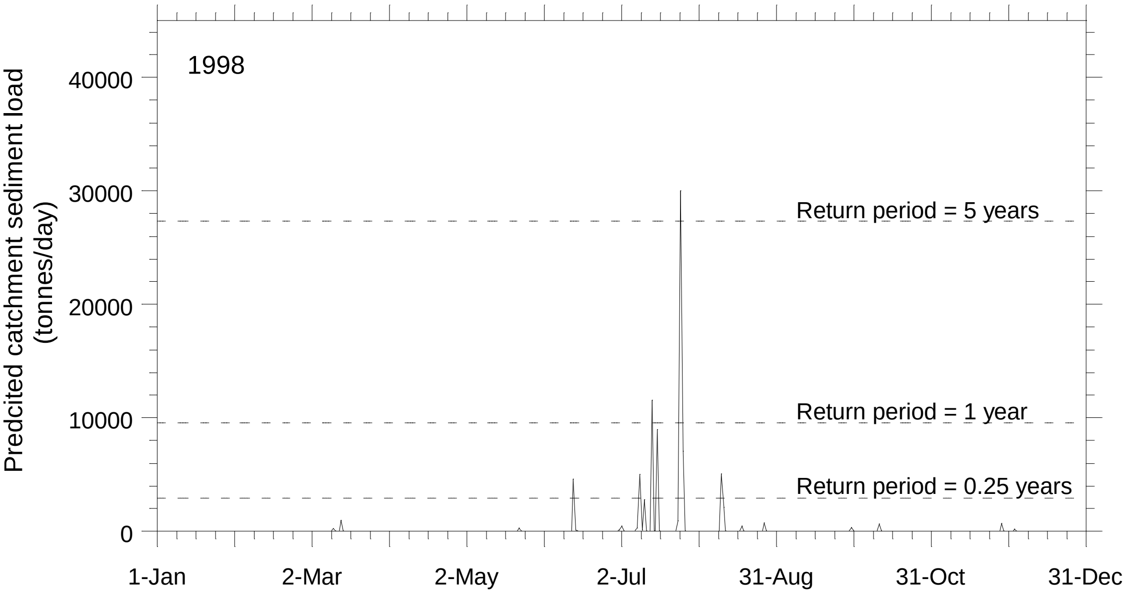
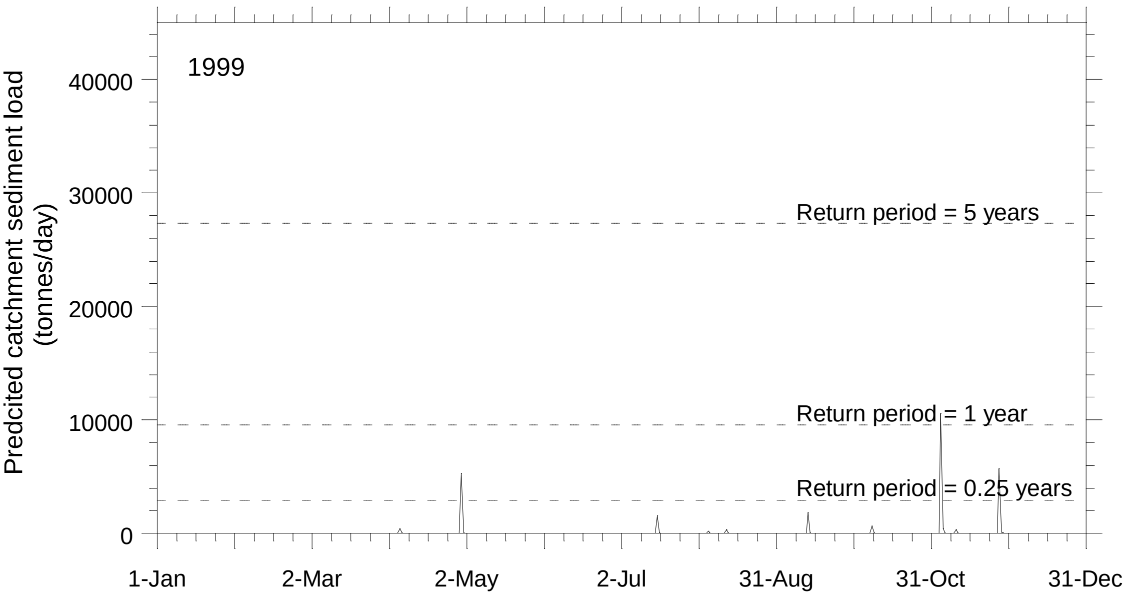
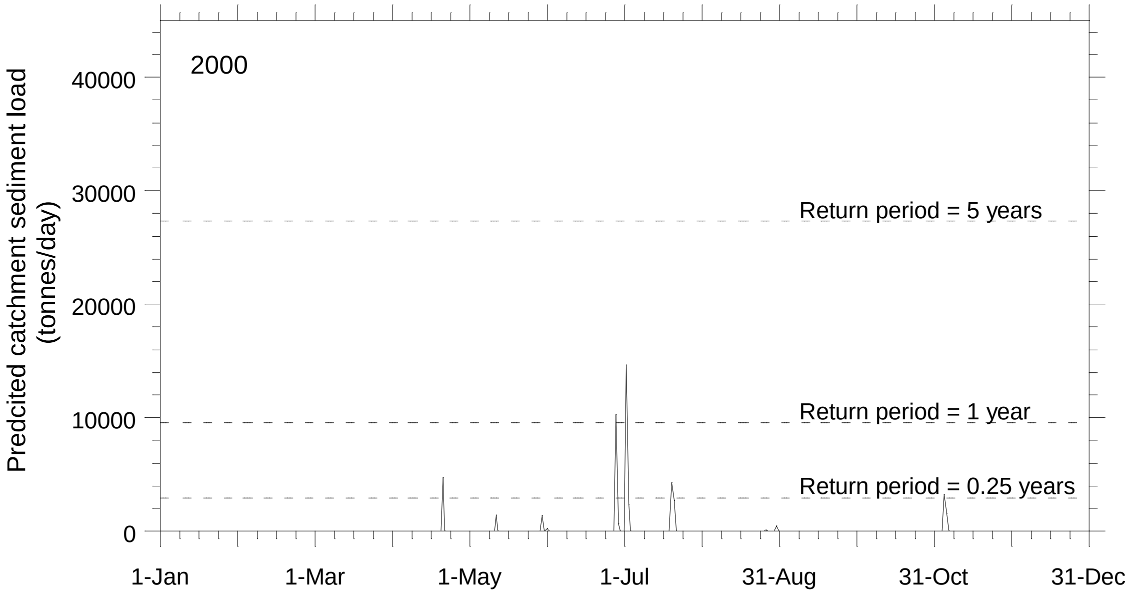
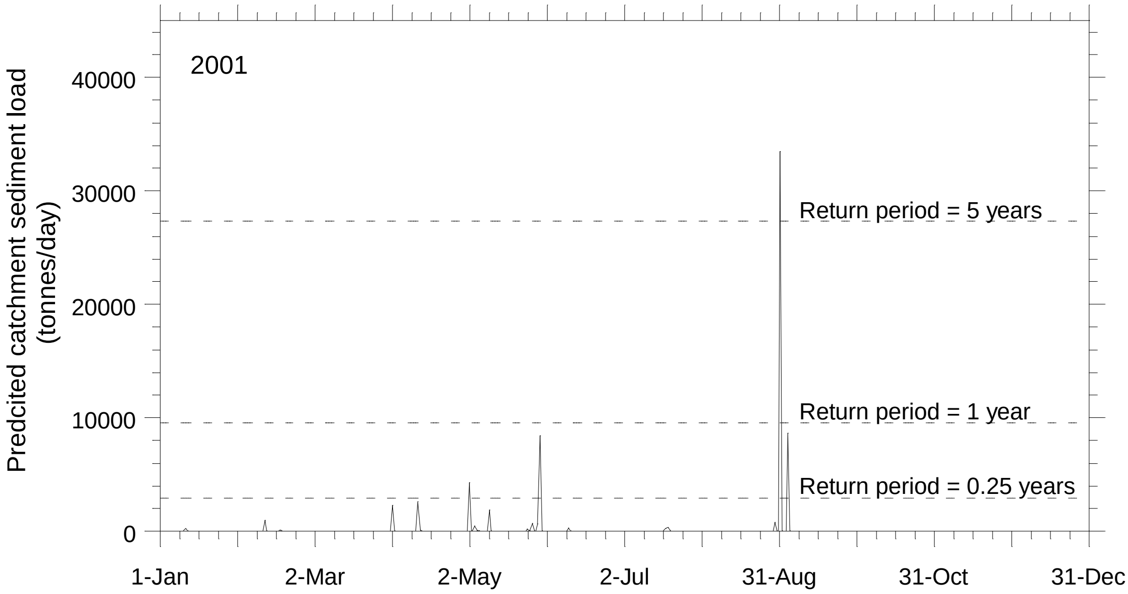
Return period = 0.25 years
1-Jan
1-Mar
1-May
1-Jul
31-Aug
31-Oct
31-Dec

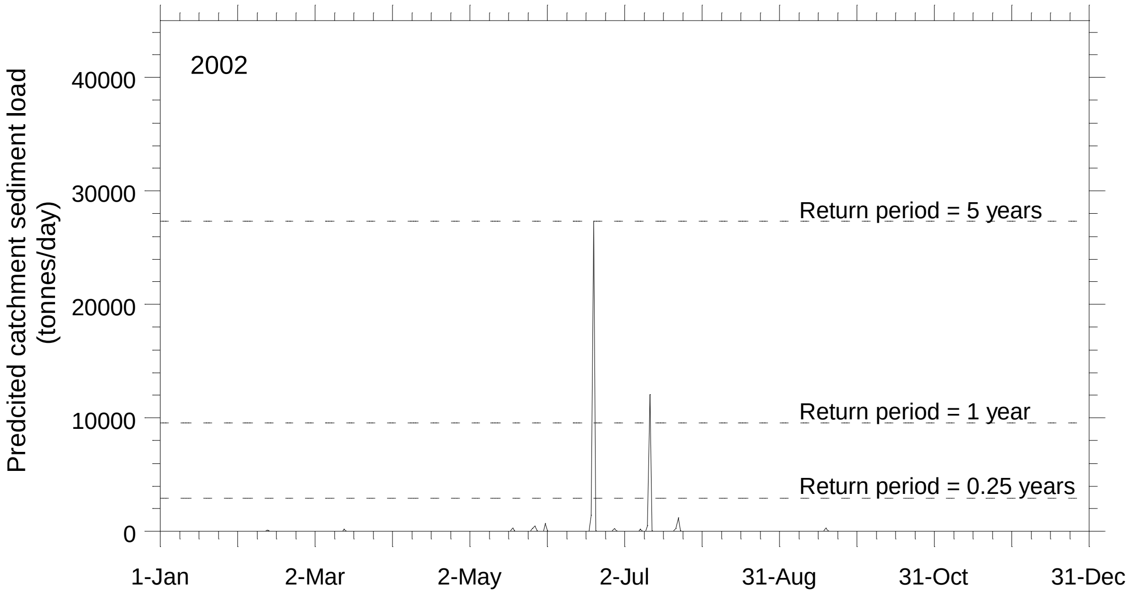

1997
Predcited catchment sediment load (tonnes/day)
Return period = 5 years
Return period = 1 year
Return period = 0.25 years
0
10000
20000
30000
40000
1-Jan
2-Mar
2-May
2-Jul
31-Aug
31-Oct
31-Dec

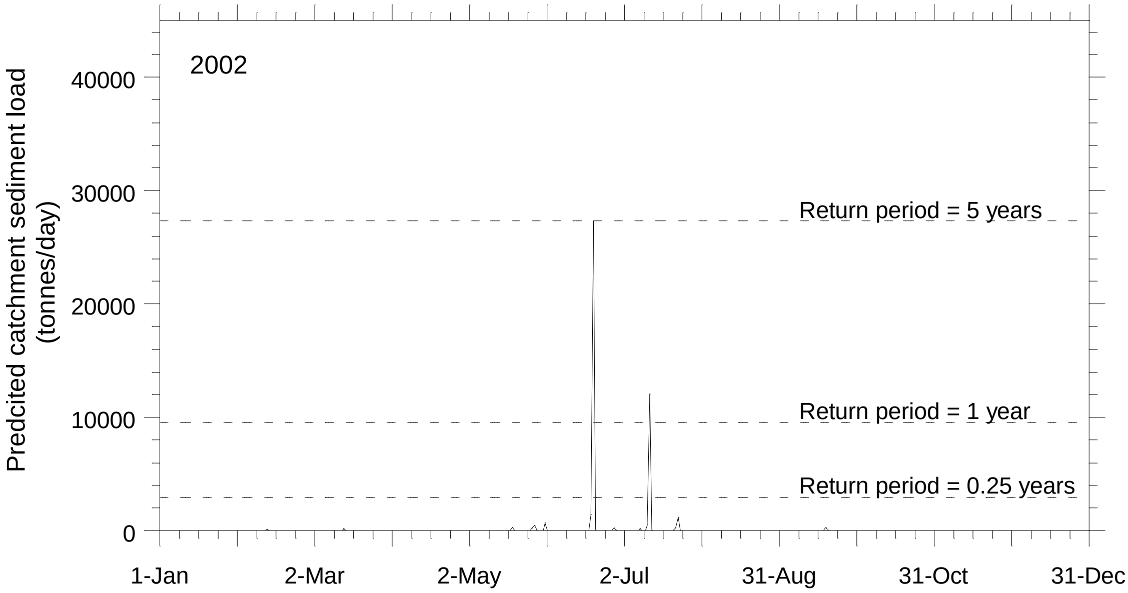

1998
Predcited catchment sediment load (tonnes/day)
Return period = 5 years
Return period = 1 year
Return period = 0.25 years
0
10000
20000
30000
40000
1-Jan
2-Mar
2-May
2-Jul
31-Aug
31-Oct
31-Dec


1999
Predcited catchment sediment load (tonnes/day)
Return period = 5 years
Return period = 1 year
Return period = 0.25 years
0
10000
20000
30000
40000
1-Jan
2-Mar
2-May
2-Jul
31-Aug
31-Oct
31-Dec


2000
Predcited catchment sediment load (tonnes/day)
0
10000
20000
30000
40000
Return period = 5 years
Return period = 1 year
Return period = 0.25 years
1-Jan
1-Mar
1-May
1-Jul
31-Aug
31-Oct
31-Dec


2001
Predcited catchment sediment load (tonnes/day)
0
10000
20000
30000
40000
Return period = 5 years
Return period = 1 year
Return period = 0.25 years
1-Jan
2-Mar
2-May
2-Jul
31-Aug
31-Oct
31-Dec


2002
Predicted catchment sediment load (tonnes/day)
0
10000
20000
30000
40000
Return period = 5 years
Return period = 1 year
Return period = 0.25 years
1-Jan
2-Mar
2-May
2-Jul
31-Aug
31-Oct
31-Dec


2002
Predcited catchment sediment load (tonnes/day)
40000
30000
20000
10000
0
Return period = 5 years
Return period = 1 year
Return period = 0.25 years
1-Jan
2-Mar
2-May
2-Jul
31-Aug
31-Oct
31-Dec