Pantanal-Taquari

Technical report on Hydro-Meteorological data processing & development of the 2D Hydrodynamic model

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1 Introduction

1.1   General

The Pantanal is the world's largest continuous freshwater wetland and is recognised as a UNESCO world natural heritage site. Its sustainability is of utmost importance but not guaranteed. Its boundaries extend across the borders of three countries: Bolivia, Brazil and Paraguay. This means that international scientific co-operation and development of mutually co-ordinated policy is important. The Pantanal is situated in the Upper Paraguay River Basin (UPRB). The processes that take place are dominated by the water dynamics in the UPRB. Development and management of the Pantanal is impossible without understanding and evaluation of the whole river basin.

Development of land use in and especially around the Pantanal is getting out of balance. Erosion in the uplands, mining, pollution, economic problems for cattle farming and a decline of biodiversity in several parts of the wetland system threaten its future. Sustainable development is possible if joint river management is developed. The objectives of the Brazilian government aim at sustainable and socially accepted policies as shows its new water legislation. Development of sustainable water management requires insight in the functioning of the system of the Pantanal and coherent data which can be used for policy development and scenario development. This project aims to contribute to the sustainable use and development of the Pantanal by:

- Developing *insight in the hydrological and land use system of the Pantanal-Taquari* to enhance sustainable water management for the Pantanal as a whole including national policies and policy options in Brazil;
- Provide insight *for policymakers and stakeholders in priorities and consequences of management options* for the Pantanal in Brazil.

Two related objectives in this project that are dealt with in this report on hydrological data processing and hydraulic modelling are:

- Development of a hydrological and hydraulic model for the Pantanal and improve the knowledge in this matter in Brazil;
- development of spatially explicit scenarios for the development of the Pantanal, based on its hydrology, biodiversity priorities, sustainable agriculture, fishing and ecotourism.

1.2   Objectives

A combined one-dimensional and two-dimensional SOBEK-model has been created as a part of the hydrological activities in this project. The SOBEK-model gives us an insight into the hydrological and hydraulic processes that play an important role in the Pantanal area.

The objectives of setting up the SOBEK-model are twofold:

- To better understand the hydrodynamic process in the Lower Taquari basin, by providing an answer to the following questions:
    - In what direction does the water flow?
    - Which areas are flooded and for how long are they flooded?
    - What are the water depths in the flooded areas?
- To obtain a tool to asses the hydrodynamic effects of possible measures (strategies) in the Lower Taquari basin

1.3   Data requirements

Data was collected to serve as input data for the SOBEK 1D2D model of the river Taquari in the Pantanal, Brazil. Data requirements for the set up of the SOBEK model are:
- Digital Elevation Model (DEM)
- Drainage network (including information about the dimensions of the network)
- Roughness estimates for the overland flows
- Inflows and outflows to and from the model; Water levels and discharges at the boundary locations (Coxim, Amolar and Porto Esperança)
- Precipitation and evaporation data of the Pantanal area

All data processing has been carried out in HYMOS. The sources of data were twofold: data downloaded from the ANA database and data supplied by Embrapa. Embrapa data were obtained through fieldwork.

1.4   Project team

The activities in this part of the project have been carried out by Bob van Kappel, Erik Mosselman and Marcel Ververs. Bob van Kappel was responsible for the hydro-meteorological data processing and for setting up the Hymos database. Marcel Ververs was responsible for the development of the 2-dimensional hydrodynamic model and for processing of the spatial data. Erik Mosselman was the project leader and he has reviewed the report.

Also Balbina Soriano and Sergio Gaudina made an important contribution to this research. They were responsible for collecting the meteorological and hydrological data respectively. Whitout this data the two dimensional hydrodynamic SOBEK model could not have been accomplished.

1.5   Further reading

In the following chapters the work that has been carried out on the data is described. In the next chapter a very detailed description is given of the data conversion and importing procedure from ANA databases to HYMOS, such that this may serve as a guideline for additional data processing.

Chapter three concentrates on the way the hydrological data were prepared with Hymos and Chapter four concentrates on the meteorological data preparation. Chapter five describes how the data for the 1-dimensional network are prepared with emphasis on the cross-sectional data.

Chapter six gives on overview of all the data needed for the SOBEK-model and it describes which data are used in the model. Calibration of the SOBEK-model is described in Chapter 7. Finally, in Chapter 8 the results of the model runs of three different scenarios are presented.

2 Importing data to HYMOS

Data were provided from different sources in different formats. The main formats are Excel spreadsheets and ANA data in an Access database.

This chapter has been written to describe the procedure that has been followed to import the ANA and other data to the HYMOS database. The description however has been made to a very high level of detail, such that it resembles a manual. This was deemed necessary, in addition to the existing HYMOS manual, and also on the request of Embrapa.

Important notice

It is very important to be critical about all data that are imported into HYMOS, irrespective of the source of the data. There are many options in HYMOS to present and screen the data for possible errors. Early detection of errors will save a lot of time later in the modelling process!

2.1   Import from ANA databases

The Agéncia Nacional de Águas (ANA) through its website supplies data in a typical database format. This format does not allow easy conversion into a format that can be used in other programmes. ANA does supply a programme to work with the data; Hidro. This program however does not provide an export facility to create easily readable files for further data processing in other systems. A conversion tool has therefore been made to read an ANA database and export selected time series data in an easily readable format. The conversion tool can also create an import file for HYMOS. A more detailed description of the conversion tool, "ExtrairDeHidro", is given in Appendix A.
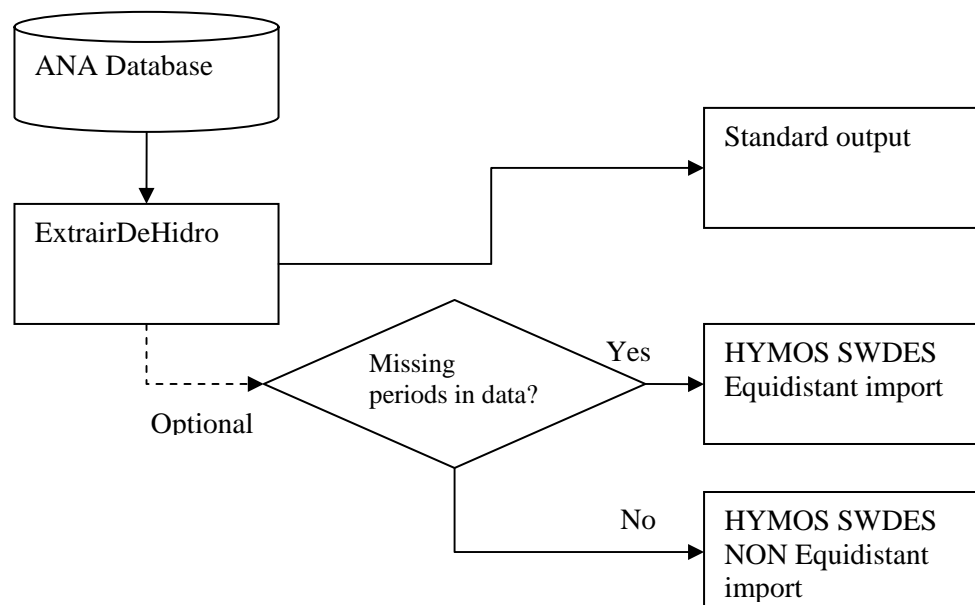
The conversion tool has been used to convert all data that had been downloaded from the ANA website. Most of the series that were converted had one or more periods of missing data, periods that are not identified as such in the database.

All output files of the conversion tool are provided in the data directory "ModelInputData".

The import procedure that was followed in HYMOS to import the data depends on whether Equidistant data or Non-Equidistant were created by the conversion tool.

Preparation before importing

Before importing it is necessary to verify that the time series that will be imported exist in the HYMOS database. Select the Location, Parameter and correct Time Base settings and verify that indeed a series exists. If this is not the case, create the series first.

Importing Equidistant data

Equidistant data import is done through the Import/Export function of HYMOS. The file type selection is SWDES Equidistant:
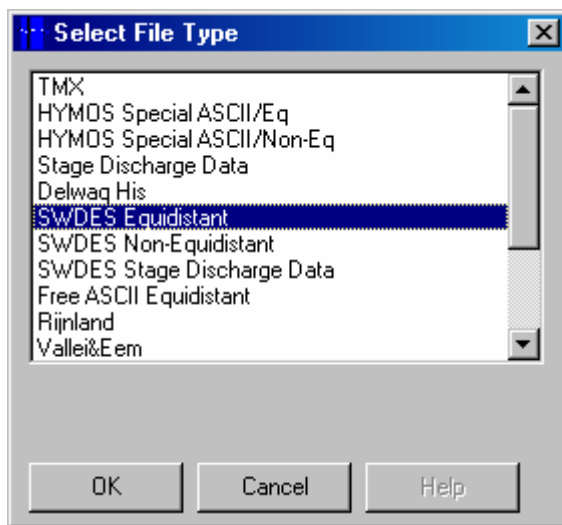
The missing data indicator in the conversion tool has been fixed to -999. The default missing data indicator in HYMOS is -999.99, but to avoid any possible problems caused by the use of a comma as a decimal separator, the missing data indicator has been set without a decimal. This requires that the missing data indicator must be changed:
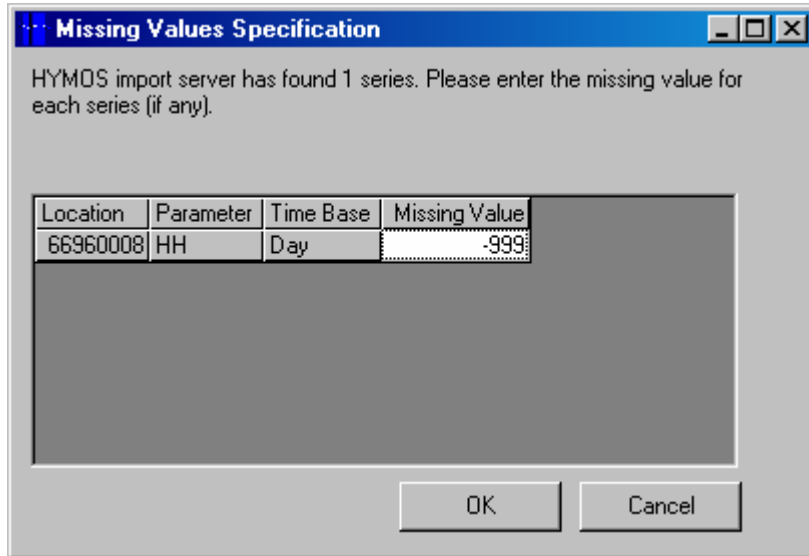
After importing the data, it is important to save the data. HYMOS will not automatically save the data. Accept the code for the series that have been imported and click on Save:

Importing NON-Equidistant data

The procedure for importing Non-Equidistant data is the same as Equidistant data. The only difference is that now the SWDES Non Equidistant file type must be selected:
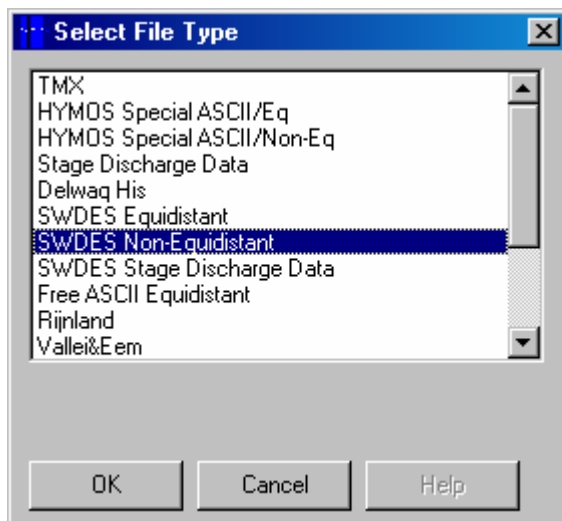
After importing and saving the data, the Non-Equidistant data must be converted to Equidistant data. This is done with the Series Transformation function, in the Data Compilation function group. See the HYMOS manual for detailed information about Series Transformation.

Some general remarks before starting the transformation:
• Check that Equidistant data selector in the Time Base settings is not selected
• Check that the Active Period settings are correct. The Start date and End date must cover the complete period or more for the imported series

Then carry out the transformation. Set the Time Base back to equidistant and verify that an equidistant series has been created.

2.2   Import from Excel

Hydrological and Meteorological data were also made available in Excel files. To import the data from the Excel files to HYMOS, multiple possibilities exist. The easiest option is to use the windows clipboard to copy / paste the data to HYMOS.

The steps to do so are:
- Select the required Location(s)
- Make sure Time Base and Active Period settings are correct
- Select the Edit Data function

Some general guidelines when importing data from Excel:
- Always verify that the series in Excel is complete: i.e. that no dates are missing. This can be done easily in Excel by not inserting the date / time by hand but by having Excel calculating the date. Errors are frequently seen, especially with leap years.
- Make sure that you have selected the entire column in the HYMOS Edit Data function, so that the data can be copied into the cells. Clicking on the cell above the column does this. The complete column will be blue.
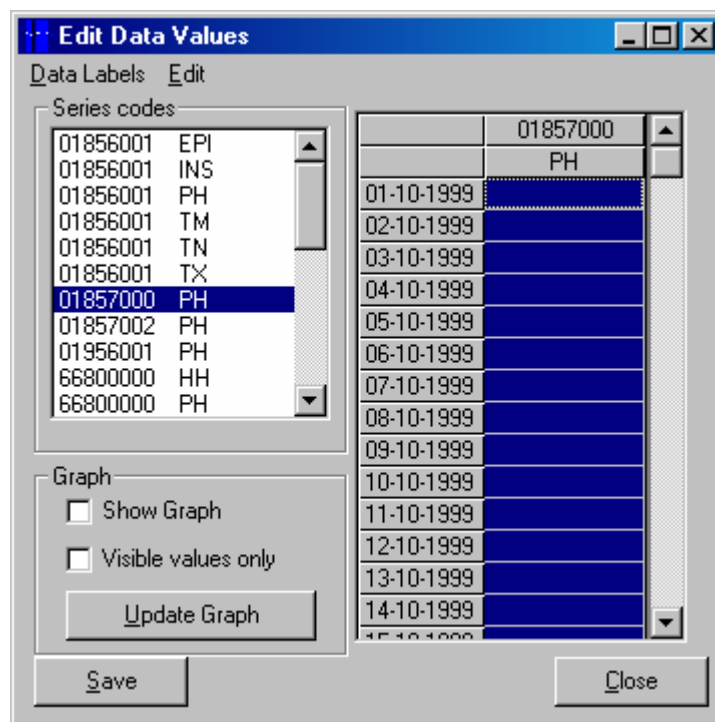
Then copy the data. Primary validation can be done by activating the Show Graph option and verifying the data that have been imported.

3 Hydrological data processing

The hydrological year that is used spans from 01 October - 30 September.

3.1   Rio Taquari

3.1.1   Coxim

Coxim (ANA ID 66870000) is an upstream boundary location for the SOBEK model. The data required are discharge data for the hydrological year 1999 - 2000, at a daily interval.

The following data were made available: (in parenthesis the HYMOS parameter)
- Water Levels (HH) : 01 Jan 1966 - 31 Dec 2002
- Discharge (QH)   : 01 Jan 1966 - 31 Dec 1995
- Discharge measurements: 36 events, starting 28 Jan 1966 - 05 Sep 2003
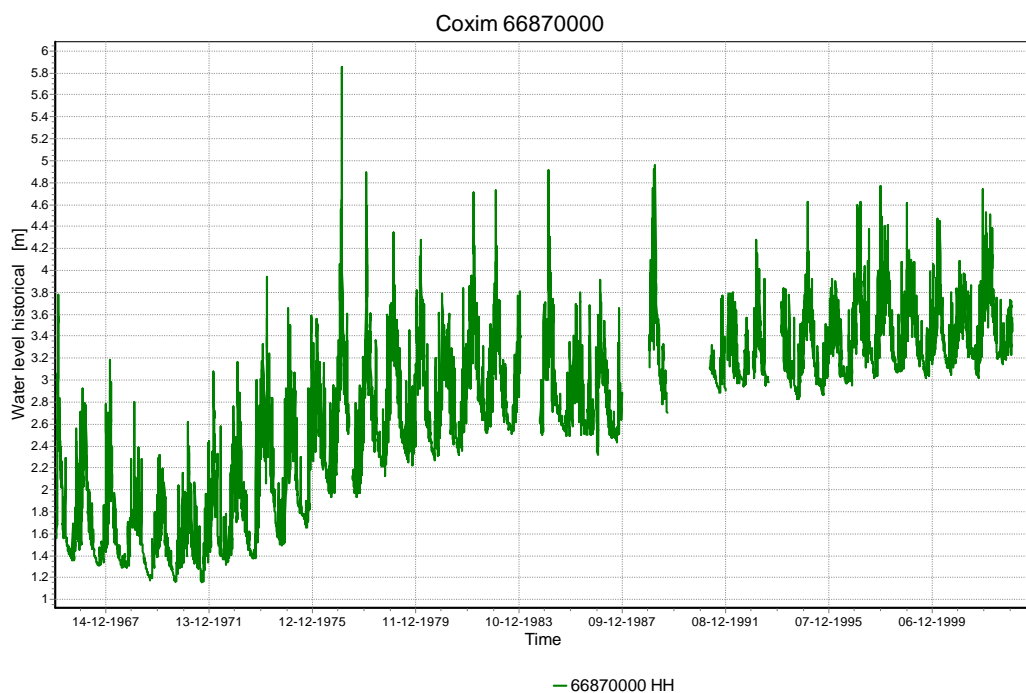
Figure 1: Water Levels at Coxim

Figure 1 one shows the original water level series as they have been obtained from ANA. A distinct trend showing a continuous rise of the lower water levels is visible.
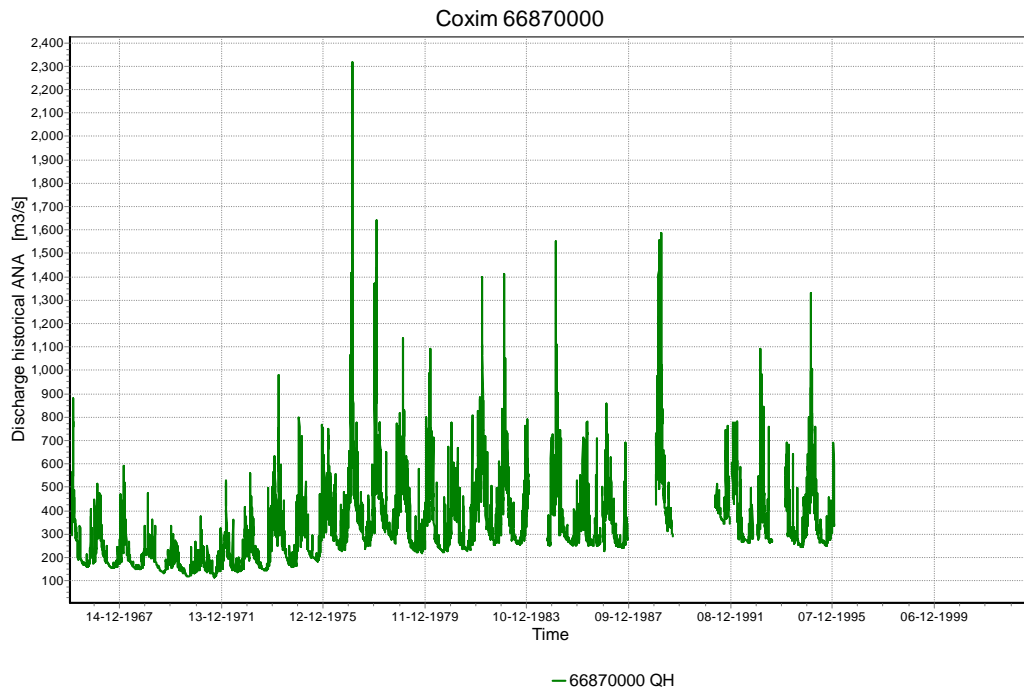
Figure 2: Discharge at Coxim

Figure 2 shows the discharge data as it has been obtained from ANA. The lower discharges show a similar, but somewhat less distinct rising trend of the minimum values. In fact, no real trend can be seen, but only a slight rising is visible in the years 1976 - 1979. Figure 2 has been made using the exact same time scale as Figure 1. Discharges for the required period of 1999 - 2000 are not available.

A rating curve for the station is not available, but discharge measurements are. Before a rating is made, a simple validation of the rating curves used for the discharges is made, by plotting Water Levels against the Discharges in a scatter plot. The scatter plot will reveal the relation that has been used to calculate Q(t) from H(t), if any.
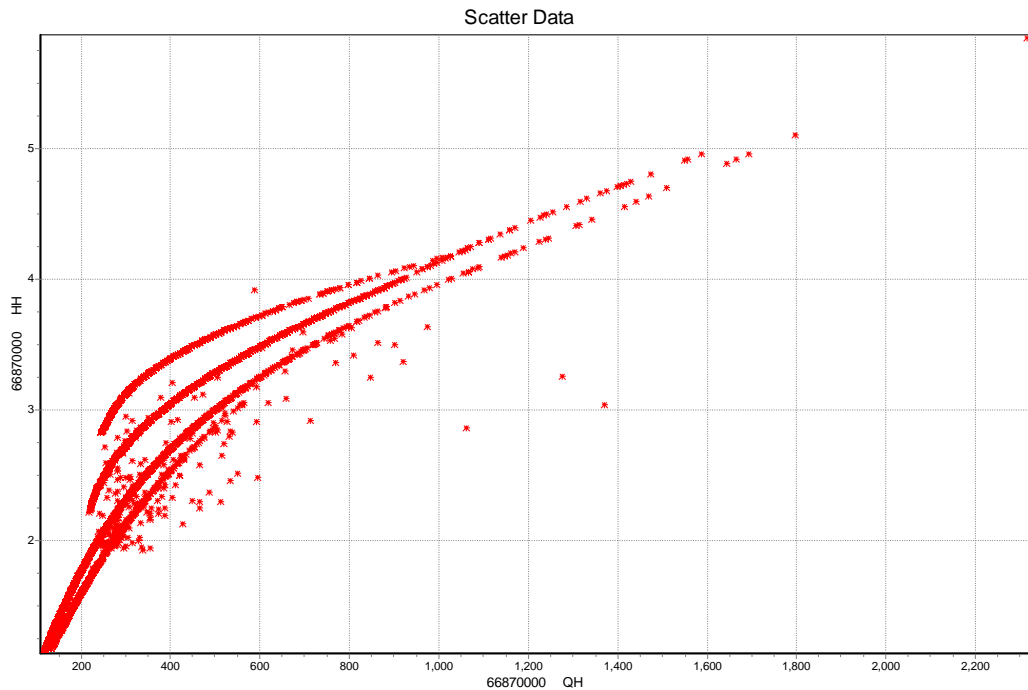
Figure 3: Scatter plot of Water levels (Horizontal axis) plotted against Discharges (vertical axis): 1966 - 1995

Figure 3 clearly shows that at least 4 distinct ratings curves have been used for the calculated discharges. Further detailed analysis has also shown that the rating curves in time shift from bottom to top (or from right to left) in the plot, indicating lower discharges at the same water level. For the period Jan 1966 to Dec 1995 the shift indicates a raised bed level of approximately 1 meter.

Questions may be raised with respect to the change in form of the topmost, and also most recent, rating curve of the period shown. The curve shows a much flatter rising limb, which would indicate a strongly widened riverbed. This is not supported by the cross-sectional information in the PCBAP report or other printed work of past field measurements.

Besides the four distinct lines, indicating rating curves that have been applied, also quite a few individual points are seen. Given that the data have been imported into HYMOS not including any estimates of doubtful data, these points give rise to additional doubts regarding the quality of the discharges provided. Further research may provide insight into this problem. At this stage this has not been carried out.

To obtain discharges for the period 1997 - 2003 the discharge measurements have been imported into HYMOS. Using the discharge measurements for the period Jan 1997 - Dec 2003, a rating curve is obtained.
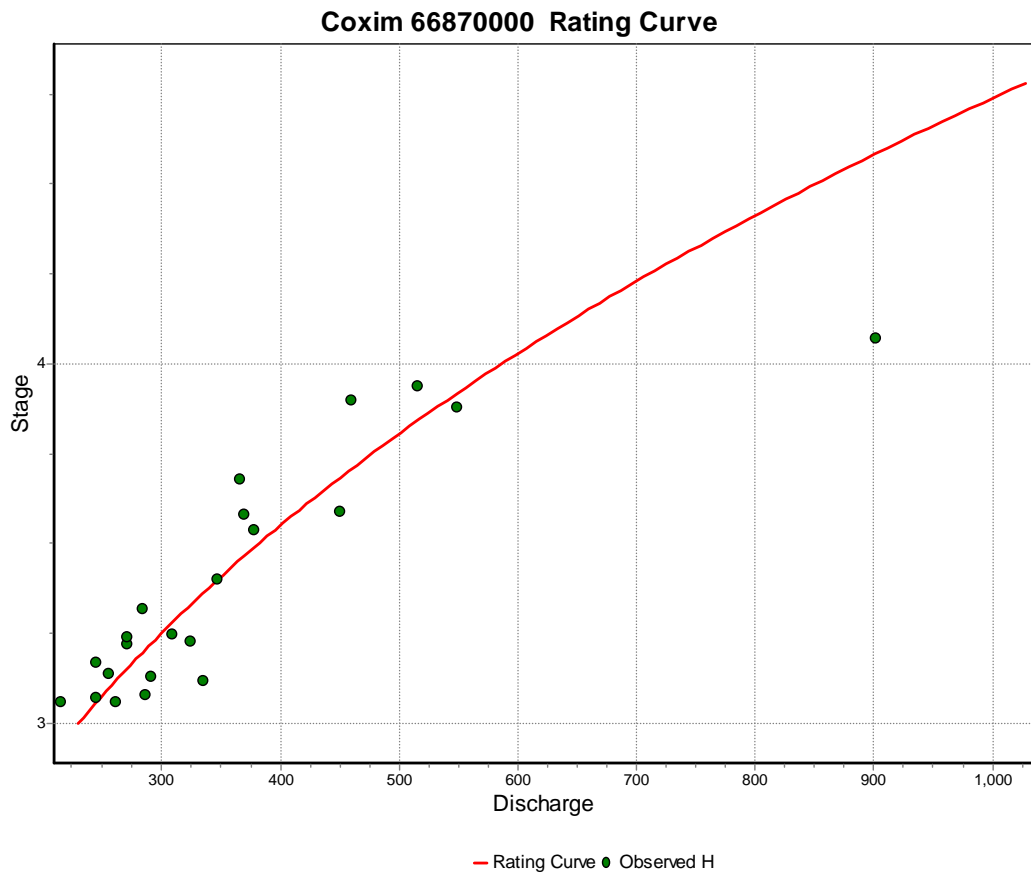
Figure 4: Rating curve for Coxim, period 1997 - 2003

It is noted that the single discharge measurement at 900 m3/s is quite far off the calculated curve. If the measurement is removed the rating curve will become slightly steeper, with lower discharge peaks. Comparing the rating curve to older discharge measurements suggests that the curve should indeed become slightly steeper, see Figure 5.
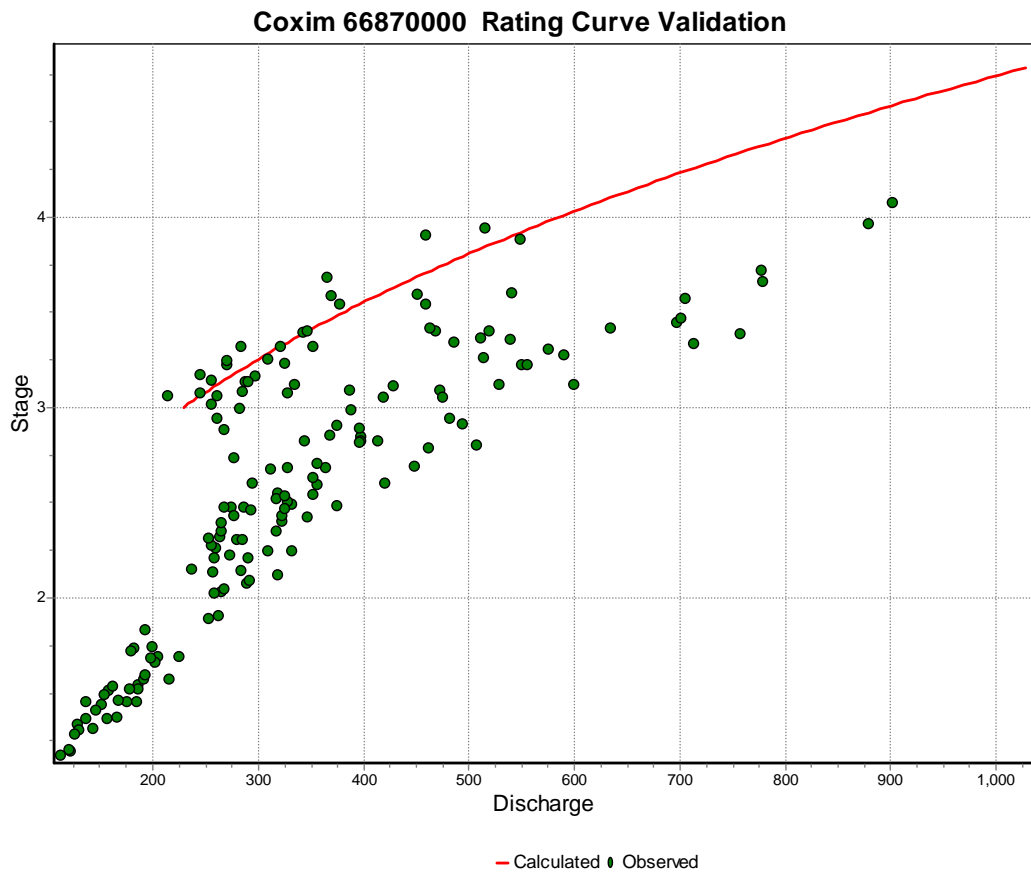
Figure 5: Coxim rating curve compared to old discharge measurements

The final rating curve is presented in Figure 6. Note the large amount of extrapolation that was needed to enable the rating curve to be used for the full range of measured water levels (3 - 4.8 m). Under optimal circumstances the extrapolation would have to be supported by at least a cross-section, the hydraulic roughness in the cross-section and the energy slope of the water level at the cross-section. In this case the data required were not available.

Note that again the rating curve minimum has shifted as compared to the rating curves shown in Figure 7. Note also that the form of the rating curve is more in line with the first curves, again shredding doubt on the last curve.

Coxim 66870000 Rating Curve
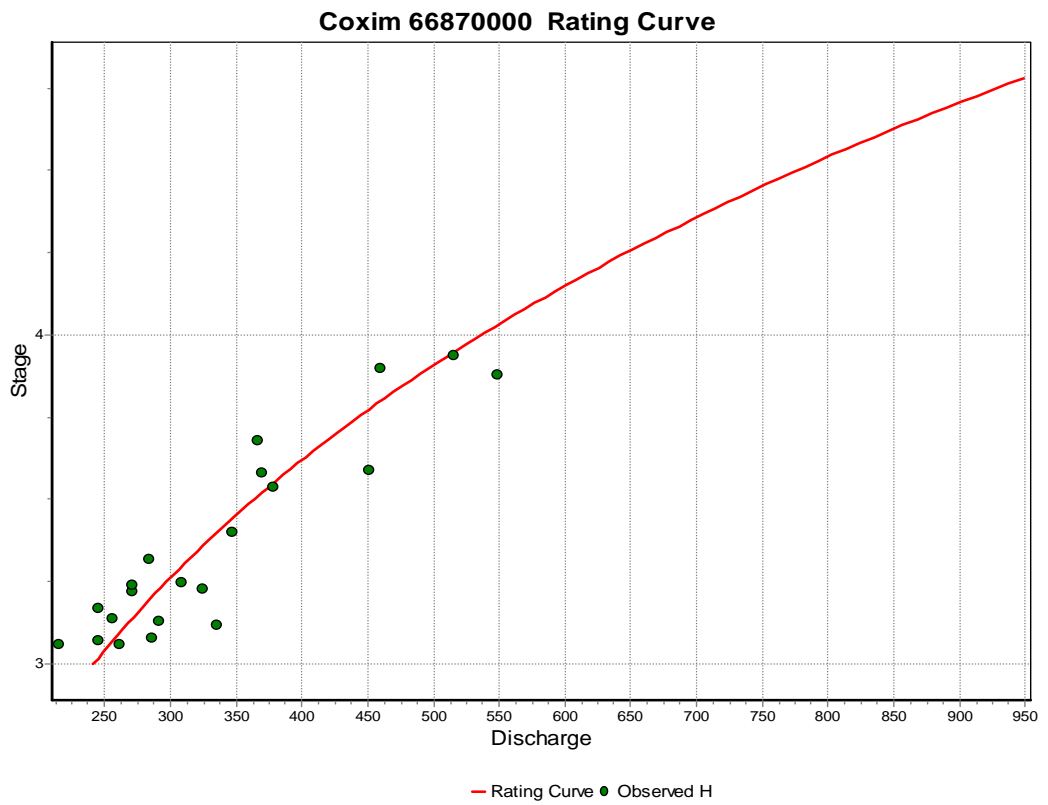
Figure 6: Coxim rating curve
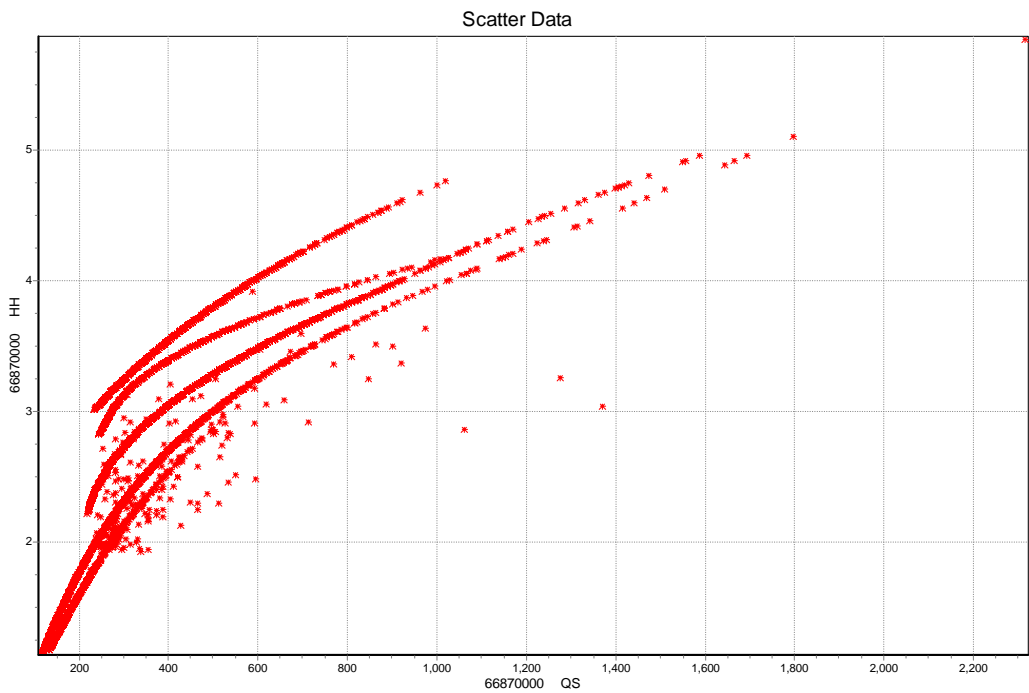
Figure 7: Scatter plot including the added rating curve

Coxim 66870000 Discharge
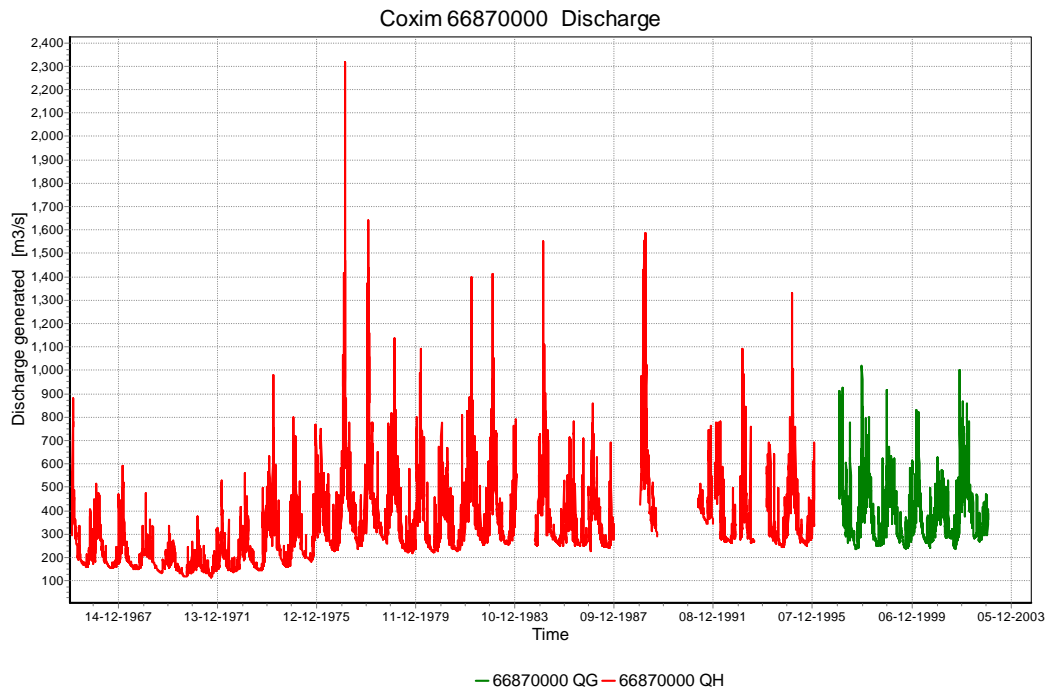
Figure 8: Generated and ANA discharges at Coxim. Newly calculated discharges (1997 - 2003) are shown in green.

Discharges were calculated using the established rating curve. The discharge that is entered into the model is shown in Figure 9.

Coxim 66870000 Discharge
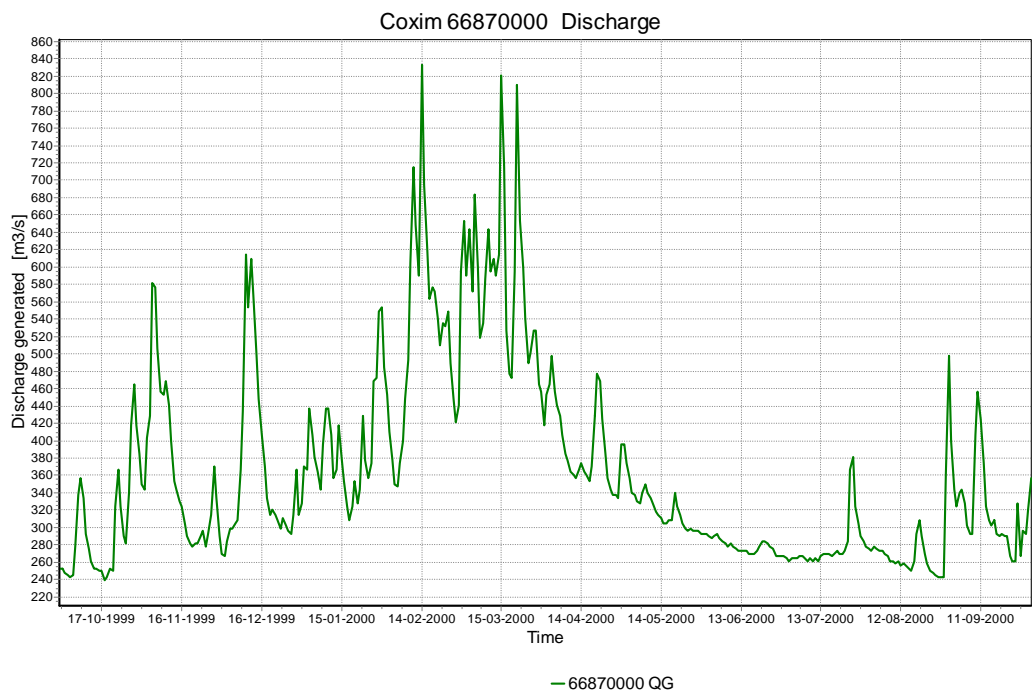
Figure 9: Discharge at Coxim for Hydrological year 1999 - 2000

3.2   Rio Paraguai

3.2.1   Amolar

Amolar (ANA ID 66800000) is an upstream boundary location for the SOBEK model. The data required are discharge data for the hydrological year 1999 - 2000, at a daily interval.

The following data were made available: (in parenthesis the HYMOS parameter)

- Water Levels (HH) : 16 Nov 1967 - 30 Nov 2003
- Discharge (QH)   : 16 Nov 1967 - 30 Nov 2003
- Discharge measurements: 66 events, starting 29 Jul 1969 - 05 Dec 2003
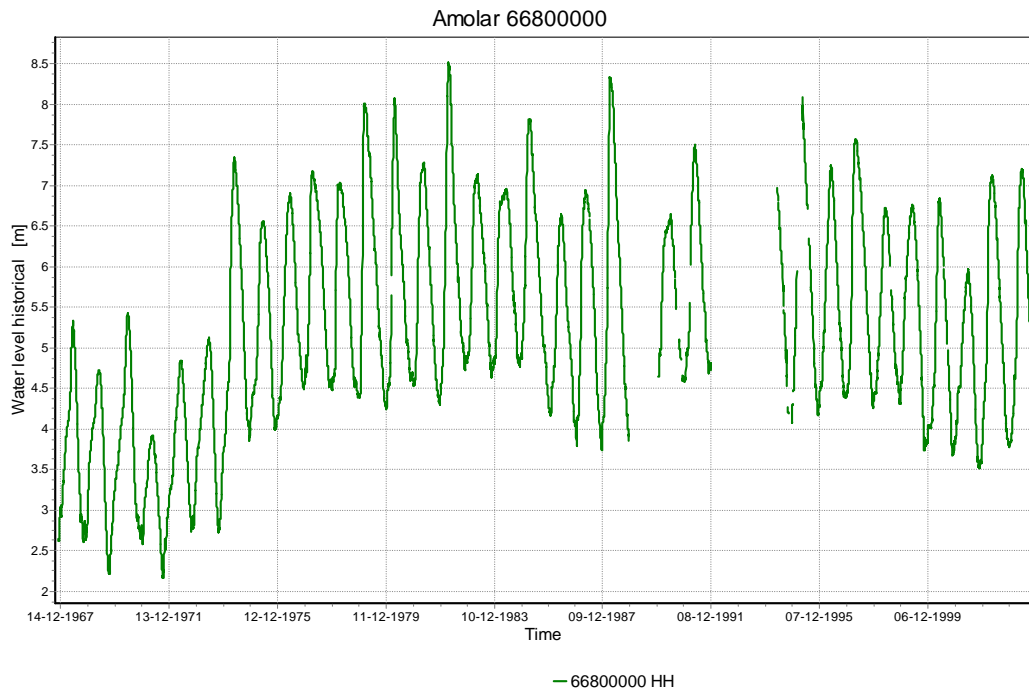
Figure 10: Water levels at Amolar

Figure 10 shows the imported water levels at Amolar. Similar to Coxim, here also a rise in minimum water levels is seen. The rise at Amolar however is seen some years before that of Coxim, notably during the years 1972 - 1975. Some periods of data are missing.
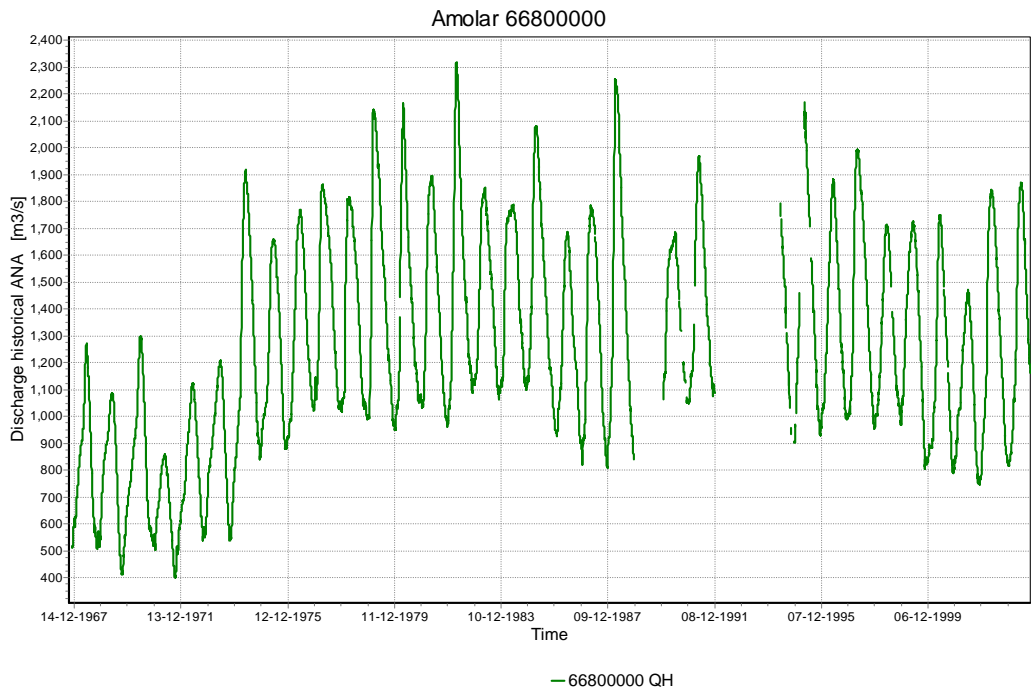
Figure 11: Discharge at Amolar

Figure 11 shows the imported discharge at Amolar. Comparing the water level series and the discharge series it is noted how very similar these appear to be.
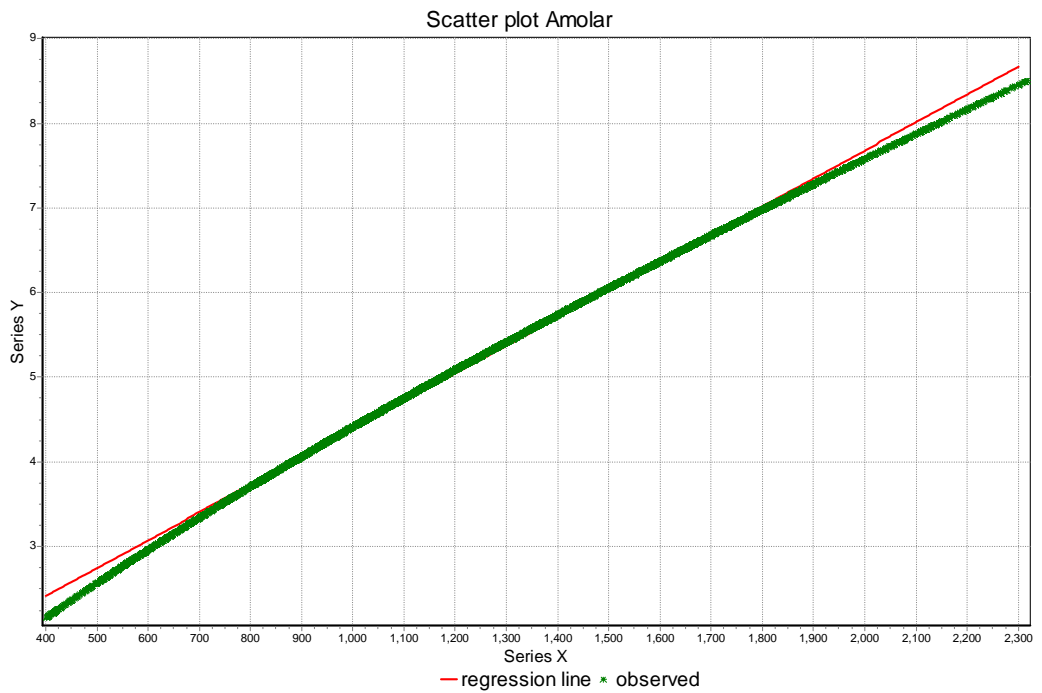
Figure 12: Comparison of applied rating curve with linear relation

Figure 12 illustrates the seemingly near linear relation between the imported discharge QH (t) and the imported water level HH (t). The green points show the rating curve as it has been applied, the red line is a first-degree polynomial (i.e. a straight line). The linearity of the rating curve is surprising.

Using the available discharge measurements, the rating curve is recreated.

Amolar 66800000 Rating Curve
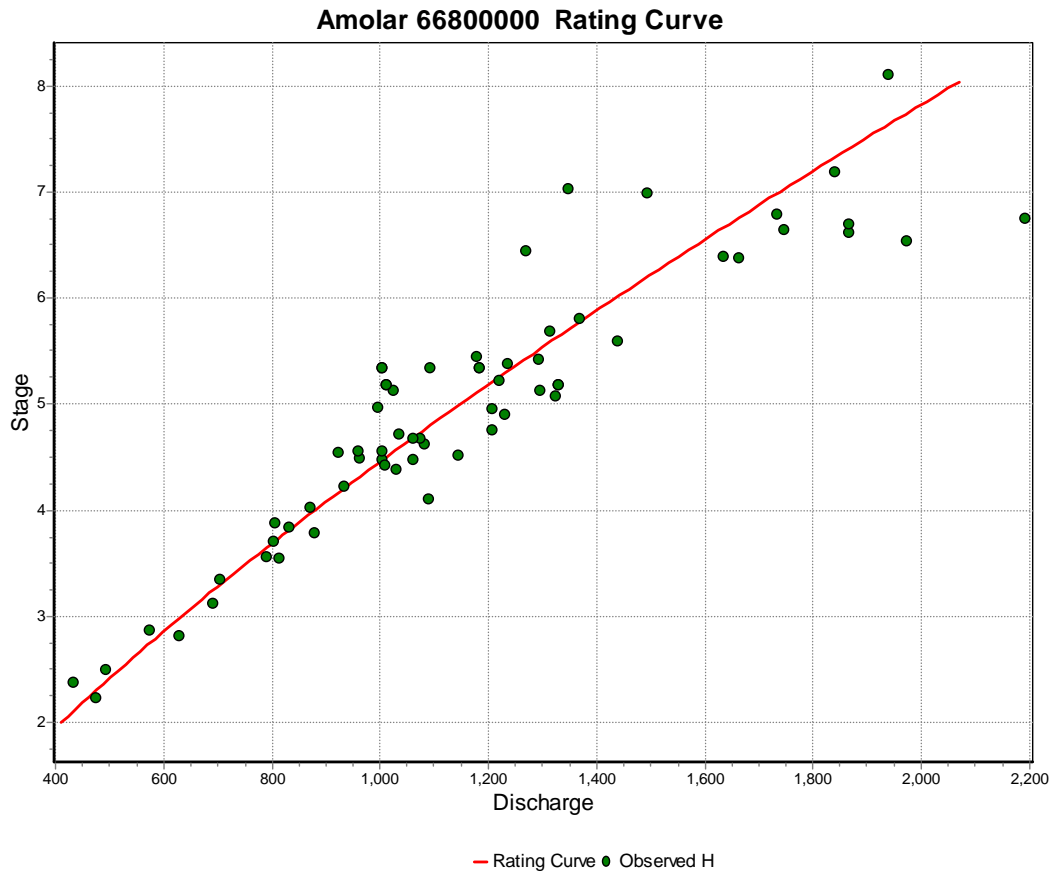
Figure 13: Calculated rating curve with discharge measurements used to derive the curve

Figure 13 shows the rating curve derived from the available discharge measurements. Some dispersion of the measurements around the regression line is seen. The derived rating curve is a power type rating curve, with a power equal to 1.3, i.e. close to linear. The derived rating curve compares very closely to the applied rating curve, indicating no apparent error in the discharges.

São Fransisco (66810000) is located approximately 60 km downstream from Amolar. This location has data for more or less the same period as Amolar and may serve to verify the discharges at Amolar.

A first comparison of imported ANA discharges for São Fransisco with those of Amolar shows a considerable difference in the discharges at the two locations.
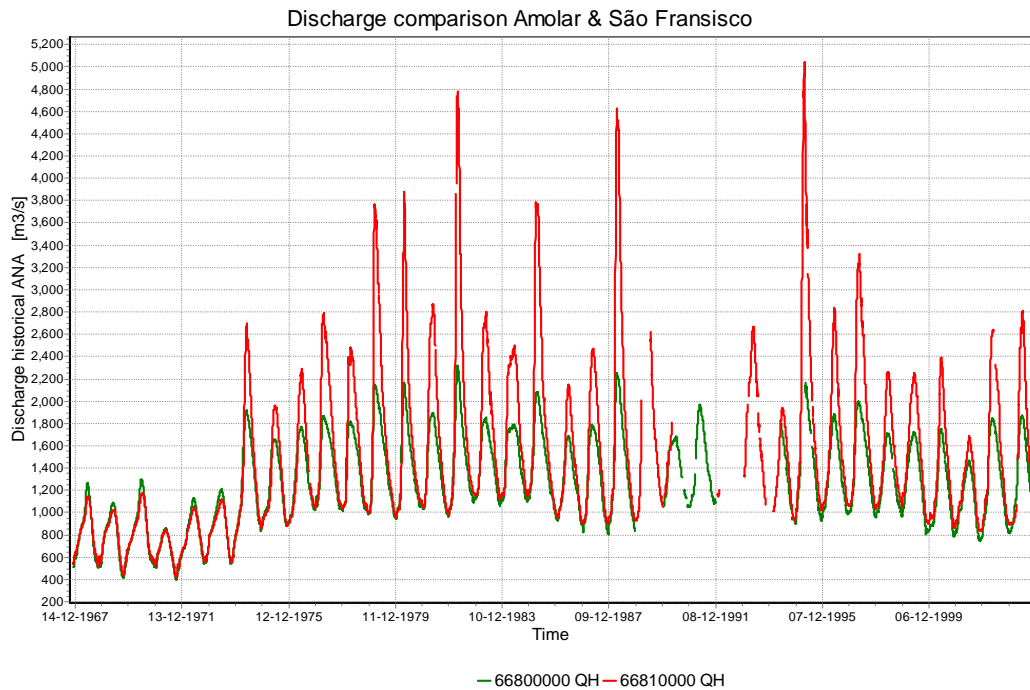
Figure 14: Comparison of discharge at Amolar & São Fransisco

Figure 14 shows the discharges at Amolar in green and the discharges at São Francisco in Red. While the lower discharges are very much similar, the higher discharges at São Francisco are considerably higher than those of Amolar. At peaks the differences can amount to a maximum of 2.800 m3/s (2.200 m3/s at Amolar and 5.000 m3/s at São Francisco in April 1995). Without a major contribution into the river Paraguai between Amolar and São Francisco, this difference in discharge is hard to explain. Further research into these differences is obviously required.

For the time being the discharge at Amolar is used for the SOBEK model. For the hydrological year 1999 - 2000 two minor periods of missing data needed to be filled. This has been done with simple linear interpolation. This leads to the following series being used at Amolar.
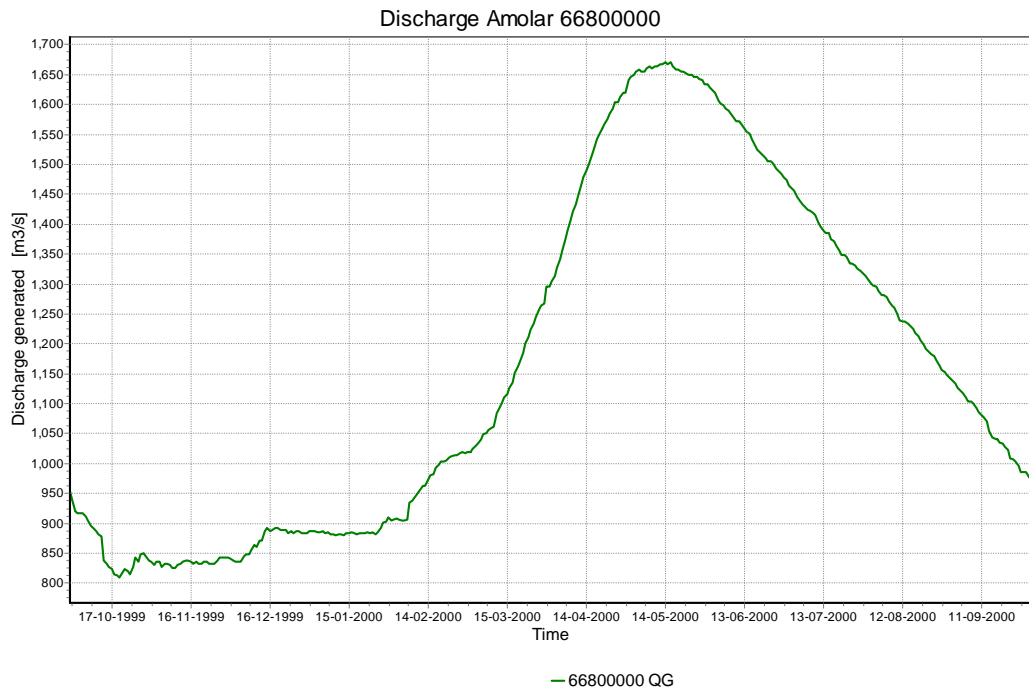
Figure 15: Discharge at Amolar for hydrological year 1999 - 2000

3.2.2   Porto Esperança

Porto Esperança (ANA ID 6696008) is the only downstream boundary location for the SOBEK model. The data required are water levels for the hydrological year 1999 - 2000, at a daily interval.

The following data were made available: (in parenthesis the HYMOS parameter)
- Water Levels (HH) : 19 Dec 1963 - 31 Oct 2003
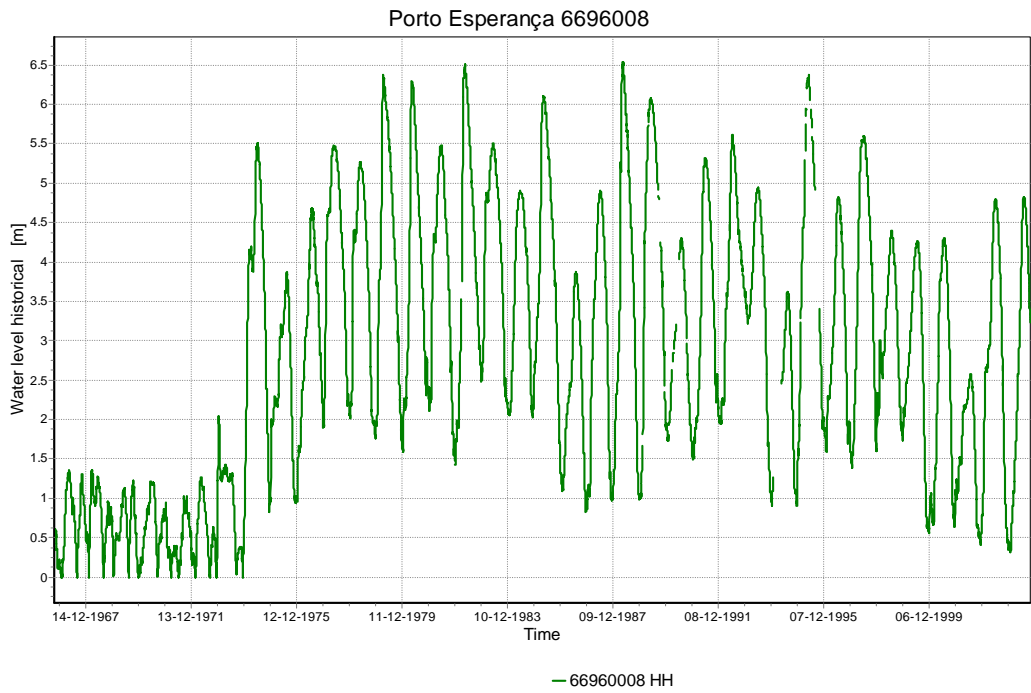- Discharge (QH)   : 19 Dec 1963 - 31 Dec 1981

Figure 16: Water levels at Porto Esperança

Figure 16 shows the water levels at Porto Esperança. A clear error in the period 1963 - Dec 1973, where water levels below the scale zero have been mirrored to positive values is visible. No further validation has been made of the Porto Esperança water levels. This leads to the following series being used in the model:
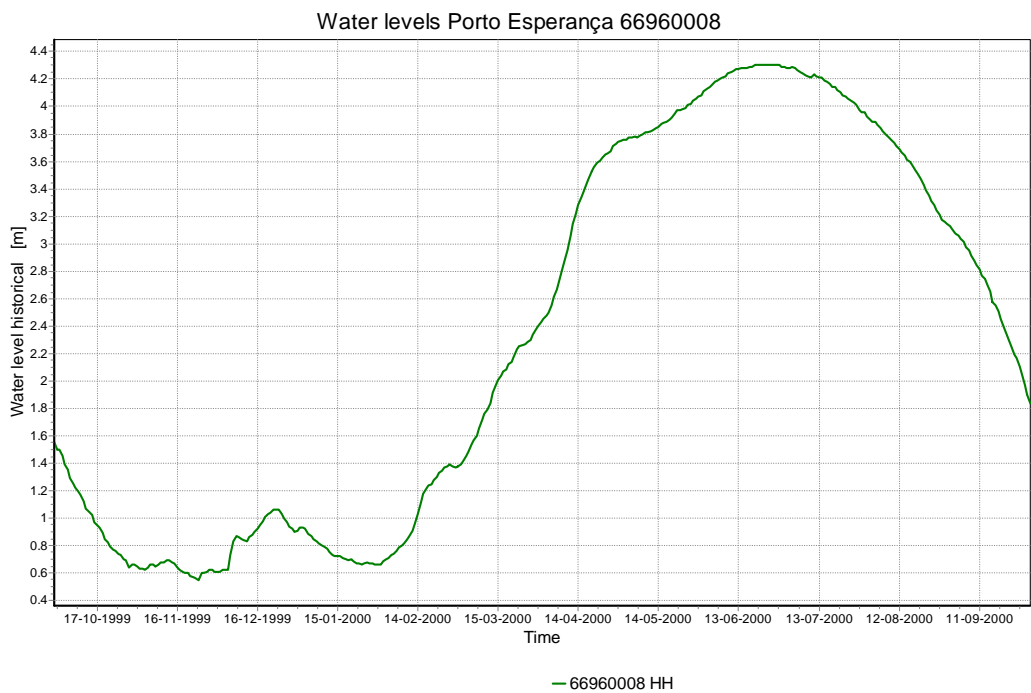
Figure 17: Water levels at Porto Esperança

3.3   Generation of Scenario Time Series

Scenario time series are required as alternative input series for the SOBEK model. The model has been calibrated on the actual series of the hydrological year 1999 - 2000. For the alternative model runs, the following alternative series are required:

- 90% dry year
- average year
- 90% wet year

The input time series for SOBEK for which alternative series are created are:

- Discharge at Coxim
- Discharge at Amolar
- Water Levels at Porto Esperança

Using the Frequency - Duration curves function in HYMOS, the required series can be generated. Setting the Time base to the Hydrological year ensures that the series that are created comply with the hydrological year.

The Frequency Curves are created for a 90% Wet, 90% Dry and an average year. For a Dry or Wet year, <u>for each day of the year</u> the function will return the value that is exceeded by 90% of all available values <u>for that day of the year</u>. The year that is obtained is therefore not a real year, but a sequence of dry, average or wet days.

3.3.1   Coxim

In Figure 18 the frequency curves for discharge at Coxim are shown. The frequency curves are derived from combined historical discharge and the discharges generated using the new rating curve. The period of data that was used is from 01 October 1966 - 01 January 2003. Besides the Wet, Dry and Average years, also the hydrograph of the 1999 - 2000 hydrological year is shown. The HYMOS series that was used is QS.

Note that the hydrographs of the frequency curves is much smoother than the hydrograph of 1999 - 2000. This is a result of the chosen procedure, in which the Dry, Wet and Average days in the year are combined into to a single year.

Figure 18 shows that a number of peak flows was higher than the 90% Wet flow for the period. On the whole 1999 - 2000 appears to be fairly wet, especially the second half of the year.
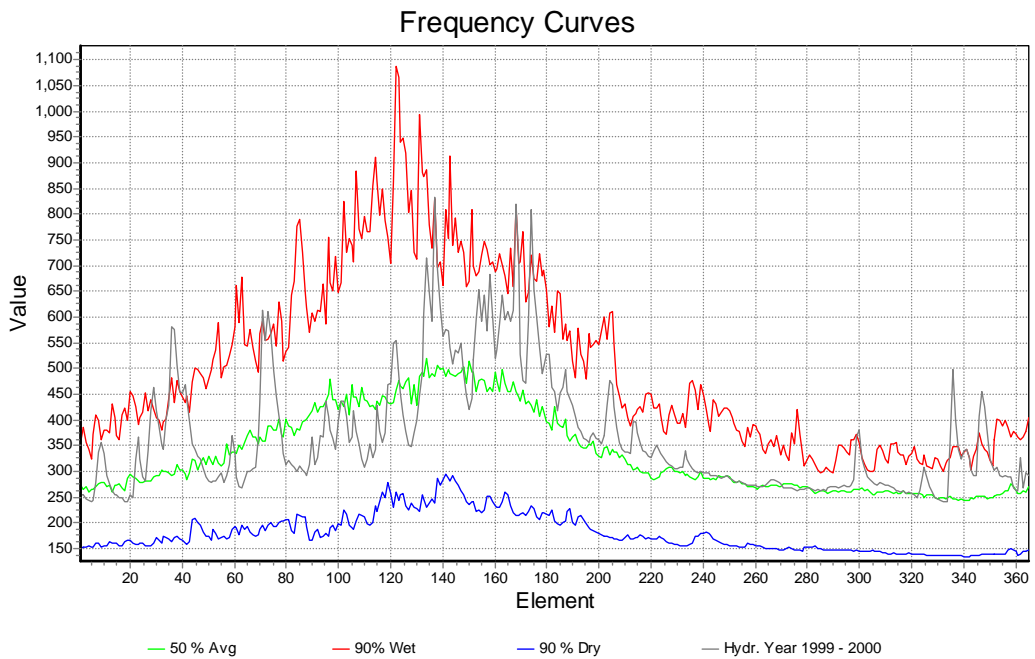
Frequency Curves

Figure 18: Hydrological year 1999-2000 and frequency curves for discharge at Coxim

3.3.2 Amolar

In Figure 19 the frequency curves for discharge at Amolar are shown. The frequency curves are derived from the discharges generated using the new rating curve. The period of data that was used is from 01 January 1969 - 01 October 2002. Besides the Wet, Dry and Average years, also the hydrograph of the 1999 - 2000 hydrological year is shown. The HYMOS series that was used is QG.

An interesting observation from the frequency curves is that the time of the peak discharge for drier years is later in the year than for wetter years.

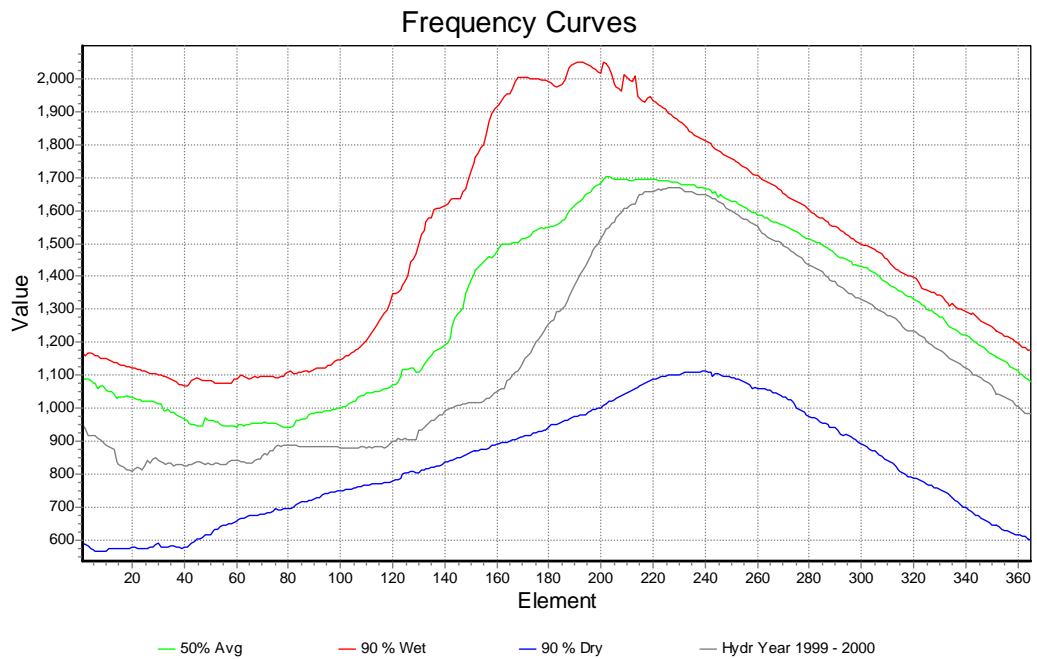The hydrological year 1999 - 2000 appears to be a below average year.

Frequency Curves

Figure 19: Frequency Curves for Discharge at Amolar

3.3.3 Porto Esperança

In Figure 20 the frequency curves for water levels at Porto Esperança are shown. The frequency curves are derived from the original water levels. The period of data that was used is from 01 January 1974 - 01 November 2003. Note that the erroneous water levels of the period up to 1974 were not used. Besides the Wet, Dry and Average years, also the hydrograph of the 1999 - 2000 hydrological year is shown. The HYMOS series that was used is HH.

The 1999 - 2000 hydrological year clearly shows the influence of the relatively wet conditions in the Taquari basin in the later half of the year. The water levels at Porto Esperança in the later half of the year exceed the average conditions, whereas at Amolar the conditions remain under the average conditions.

The sudden drop in dry conditions seen around day 200 - day 220, or more or less in April, seems somewhat strange. Further research into the time series may be required to explain this, if it cannot be explained simply by an error in the time series. No further analysis has been made yet. The same is true for the downward spike around day 150.
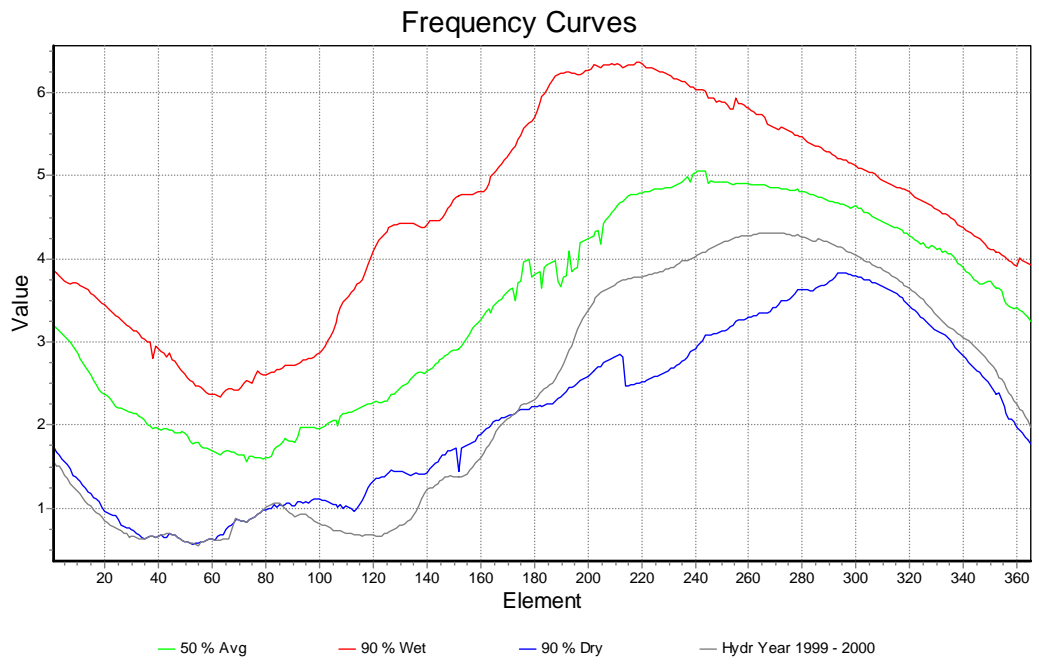
Figure 20: Frequency Curves for Water Levels at Porto Esperança

4 Meteorological data processing

Meteorological data in the SOBEK model are applied using a single time series that represents the areal average of the parameter concerned. For the model that has been set up only precipitation and evaporation has been used.

4.1   Precipitation data

Precipitation data are available for a number of locations within and in close proximity of the Pantanal. Most series, however, have significant periods of missing data, illustrated in Figure 21.

Figure 21: Data availability of 11 Precipitation data series

Only two stations show complete data series, for the period covering beginning 1979 to end 2001. The two stations are Itiquira (017540000) in red and Nhumirim (01856001) in blue.

The two series show a high degree of consistency, as is demonstrated by the double mass curve presented in Figure 22. Itiquira does show considerably more precipitation than Nhumirim, as illustrated in Figure 23.
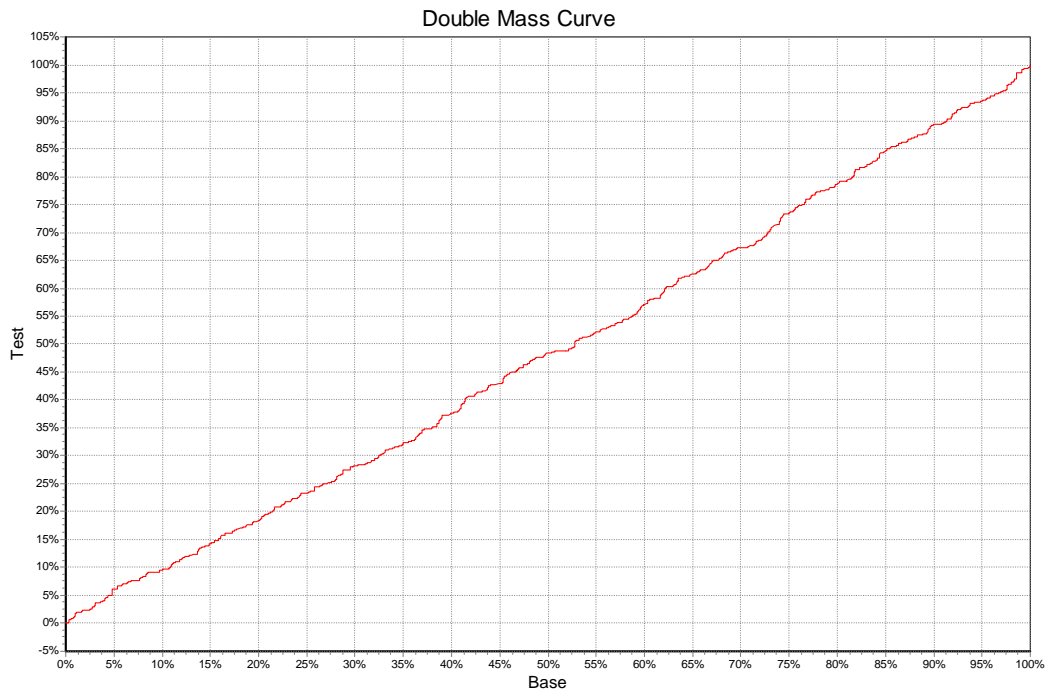
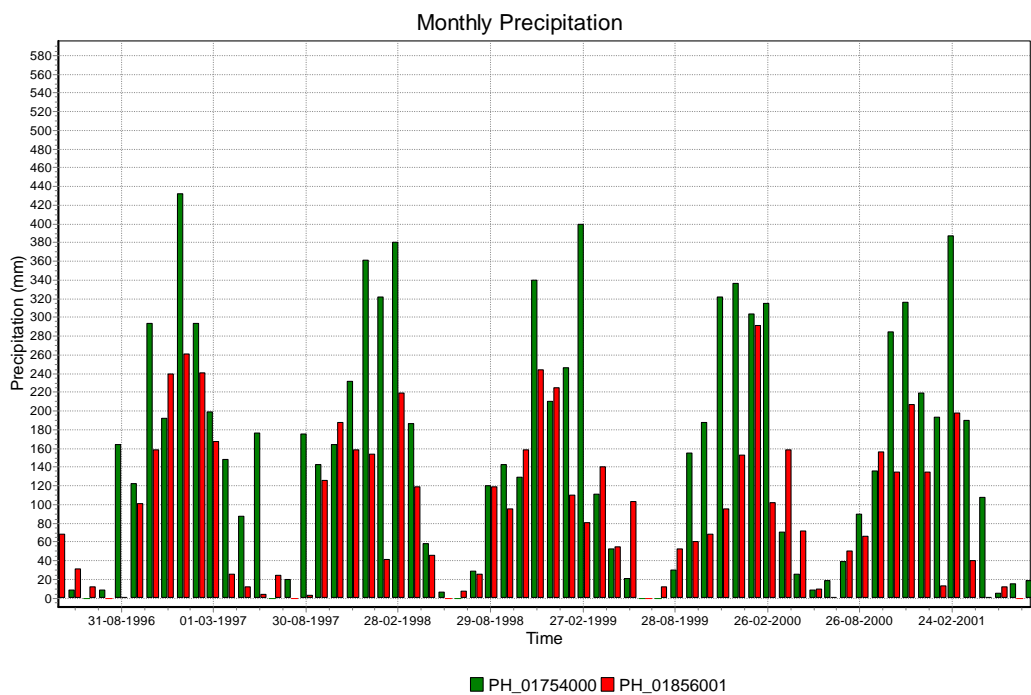Figure 22: Double Mass curve of Itiquira and Nhumirim

Figure 23: Monthly precipitation at Itiquira (Green) and Nhumirim (Red)

For the SOBEK model a straightforward linear average has been made of the two series. It is assumed that for the moment this provides a sufficiently good estimate of the areal rainfall of the Pantanal. For the hydrological year 1999 - 2000 this results in the following series being used:
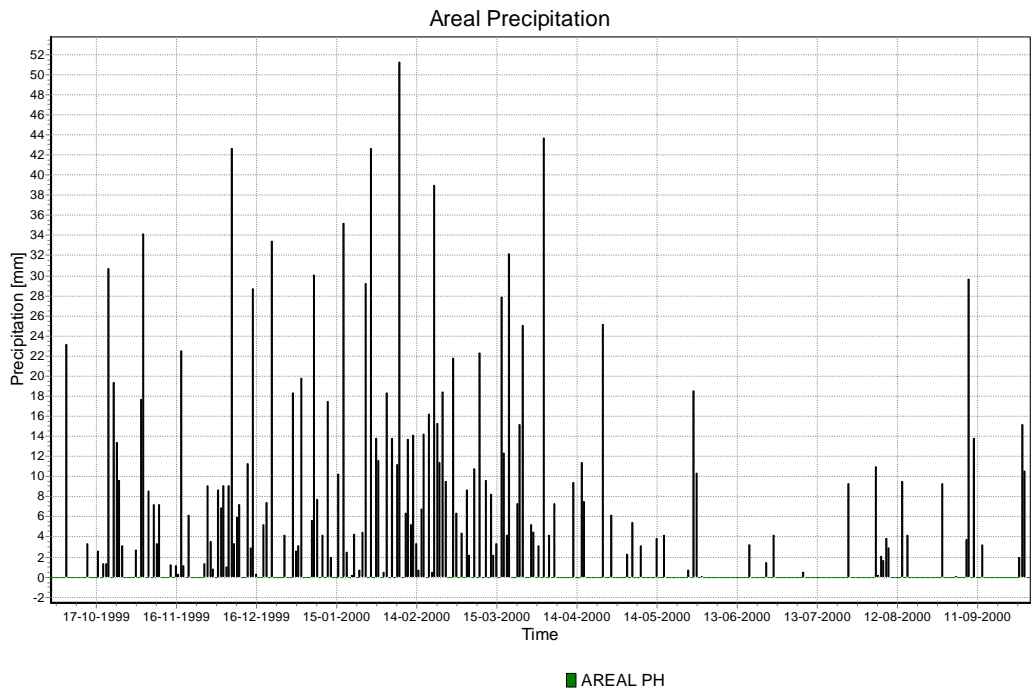
Areal Precipitation

Figure 24: Areal Precipitation

4.2 Evaporation data

Evaporation data are available only at station Nhumirim. The complete series is shown in Figure 25.
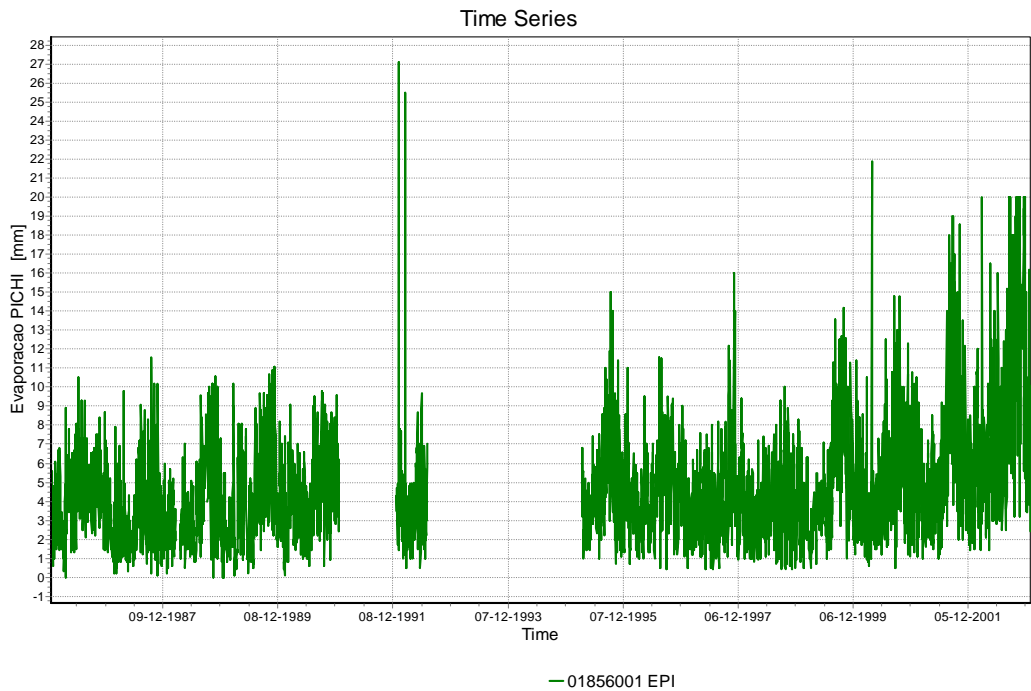
Figure 25: Daily evaporation at Nhumirim, Jan 1986 - Dec 2002

Figure 25 shows a probably serious problem starting around July 1999, when daily evaporation values seem to start rising, and continue to rise. This is clearly illustrated, when the moving average of the daily series for a period of 60 days is plotted in the same graph, see Figure 26
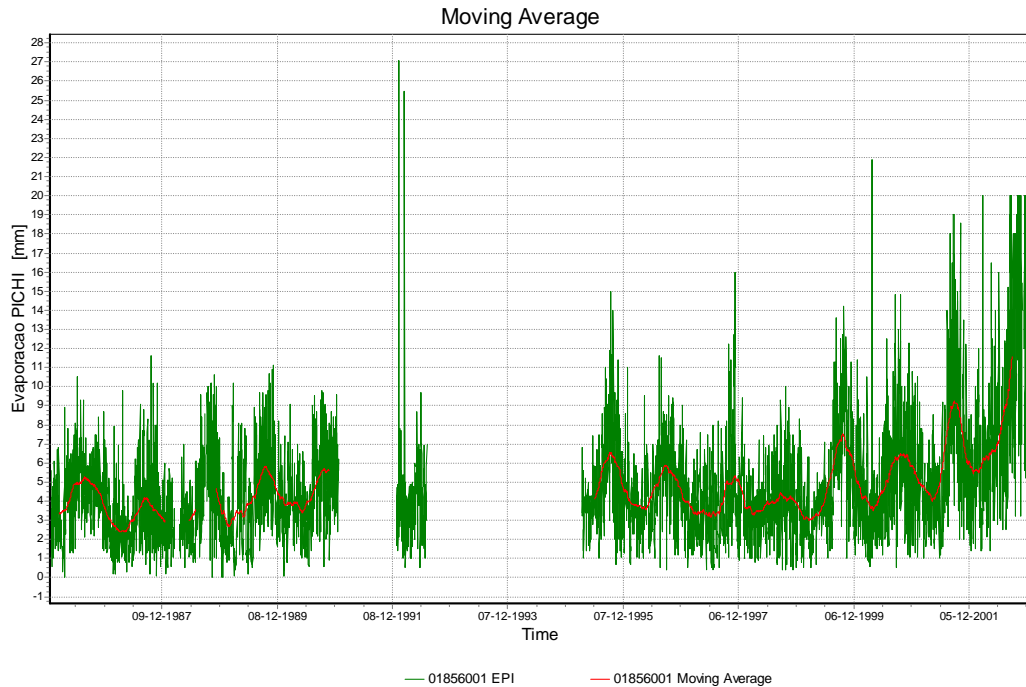

Figure 26: Daily evaporation including 60 day moving average

The problem may be caused by a change in the calculation procedure. However, this could not be confirmed and needs to be verified.

Meanwhile the evaporation data used in the model are the 60 day moving average for the hydrological year 1996 - 1997, assuming that this daily evaporation value is representative for the area as a whole.
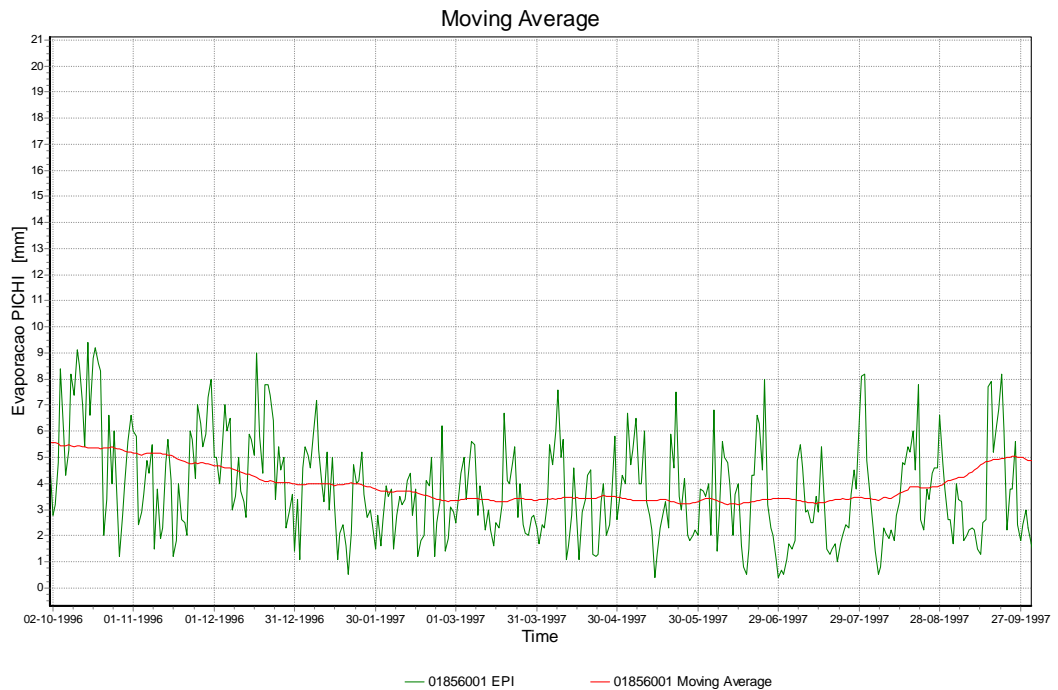
Figure 27: Evaporation for Oct 1996 - Oct 1997 including evaporation profile (60 day moving average)

4.3   Generation of Scenario Time Series

Scenario time series are required as alternative input series for the SOBEK model. See also section 3.3. The meteorological input data for the SOBEK model are catchment average rainfall and evaporation.

Precipitation data are obtained as an average of two time series. For this average series the frequency curves can be established. For the evaporation series no scenario time series are required because the evaporation data used in the SOBEK model are regarded as potential evaporation.

4.3.1   Precipitation

If the frequency curves for precipitation data would be established in the same manner as for the water levels and discharges, most or even all the 90% dry values would be equal to zero and the 90% wet values would show precipitation at most or all days. This is clearly not correct. The reason for this is that precipitation data are not continuous. In order to obtain a reasonable estimate the following procedure has been used:

1. establish the monthly sums for the precipitation series.
2. obtain the frequency curves for the monthly sums.
3. upscale or downscale the values of the 1999 - 2000 hydrological year such that the monthly sum represents the dry, average of wet frequency curve.

Note that this procedure is very rough. The number of rainy days in each month remains the same, which is obviously a simplification of the actual situation.

In Figure 28 the frequency curves for monthly precipitation of the areal average are shown. The period of data used is from 01 January 1979 - 01 January 2002. The HYMOS series that was used is Areal PH.
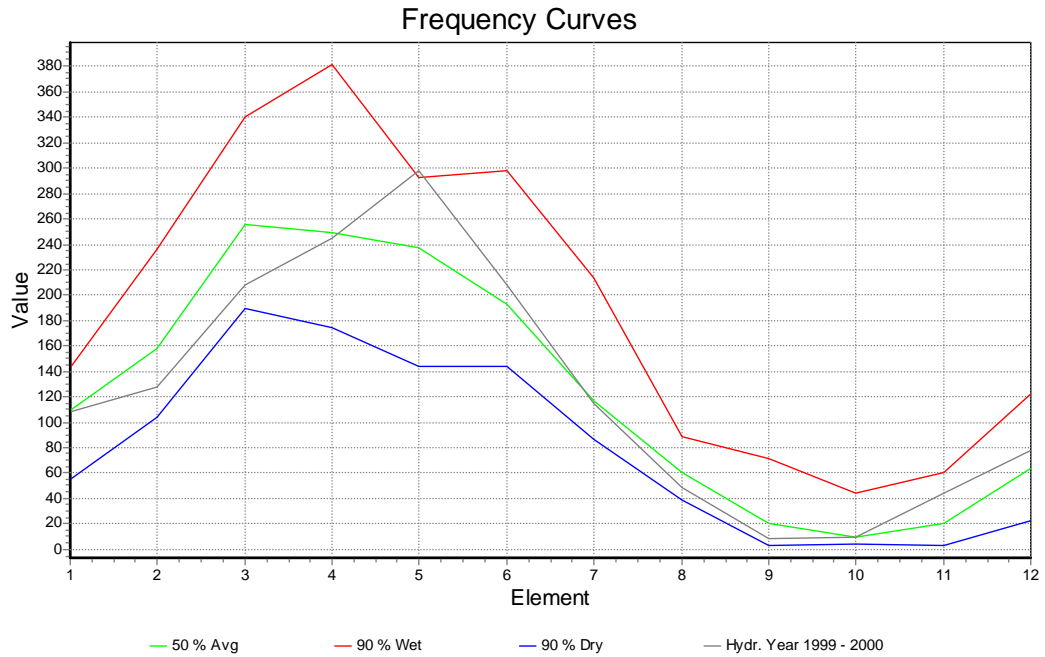

Figure 28: Frequency curves of monthly precipitation

Based on the above frequency curves, the daily values for an average, dry and wet year were established. The upscaling or downscaling of the data has been carried out in Excel.

5 Cross-sectional data

Cross-sectional data are used in the SOBEK-model to give the river channel its dimensions. For each cross-section, information on geographical location, elevation and width is needed. The elevation of the cross-sections can be expressed with absolute values or through relative values with respect to a local reference level derived for example from the DEM. The data for cross-sections were obtained from three different data sources, namely:

- The ANA Database
- A PCBAP report
- Field measurements (dataset from Carlos Padovani)

For the Paraguai river only data from the ANA database were available and for the Taquari river data from all three sources. In total for twenty-two locations cross-sectional data were available, measured for several points of time. Figure 29 shows the locations for which cross-sections were available.
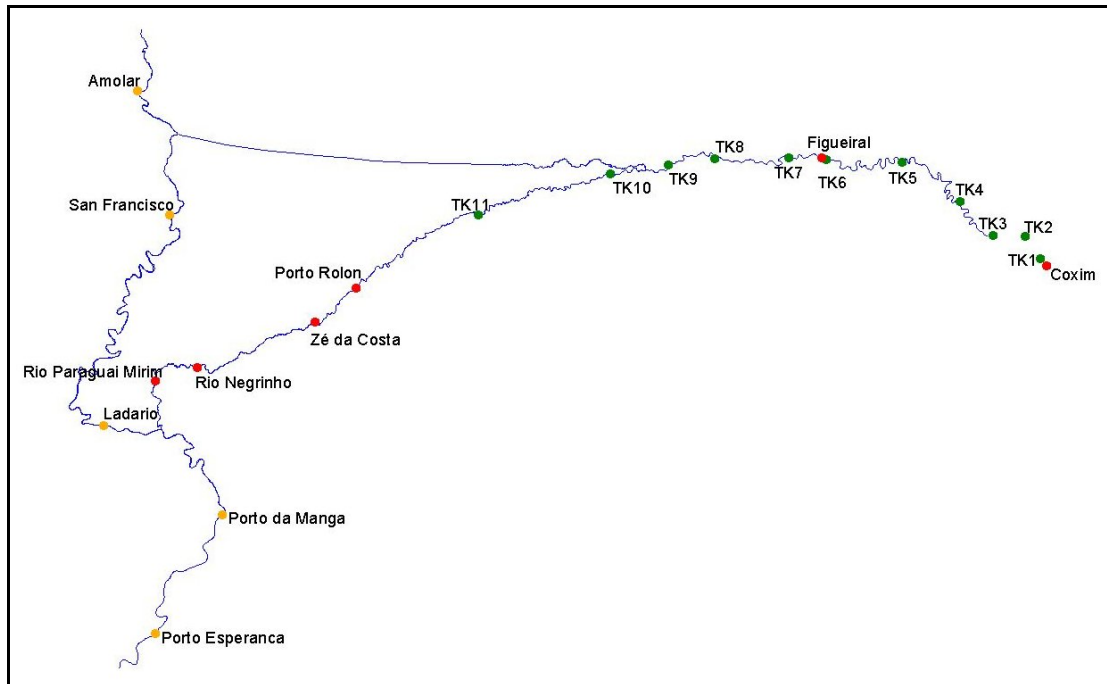

Figure 29 Locations where cross-sections are available for the river Paraguai and Taquari

The data from the PCBAP report were digitised first by a student. The data from the ANA database and from field measurements were digitally available, but had to be converted to a format used by SOBEK. The cross-sections were converted using an Excel spreadsheet. SOBEK uses a format, in which cross-sections are described by elevation values and corresponding distances from the left bank.

5.1   Rio Taquari

5.1.1   Coxim

Coxim is an upstream boundary location for the SOBEK model. Exactly at that point, it is not possible to enter data for a cross-section in the SOBEK model, so a cross-section location was added just downstream of the upstream boundary at Coxim. For this cross-section location the data from the ANA database on Coxim for 24th of August 1999 was used. Figure 30 shows the data for the cross-section at Coxim.
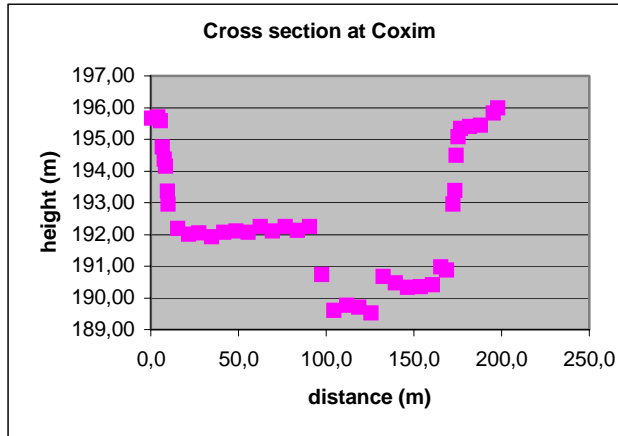

Figure 30 Cross-section at Coxim

5.1.2   Other locations

Between Coxim and the confluence with the river Paraguai, 15 cross-section points have been added to the SOBEK model. The cross-section points obtained from field measurements are given in Figure 31.
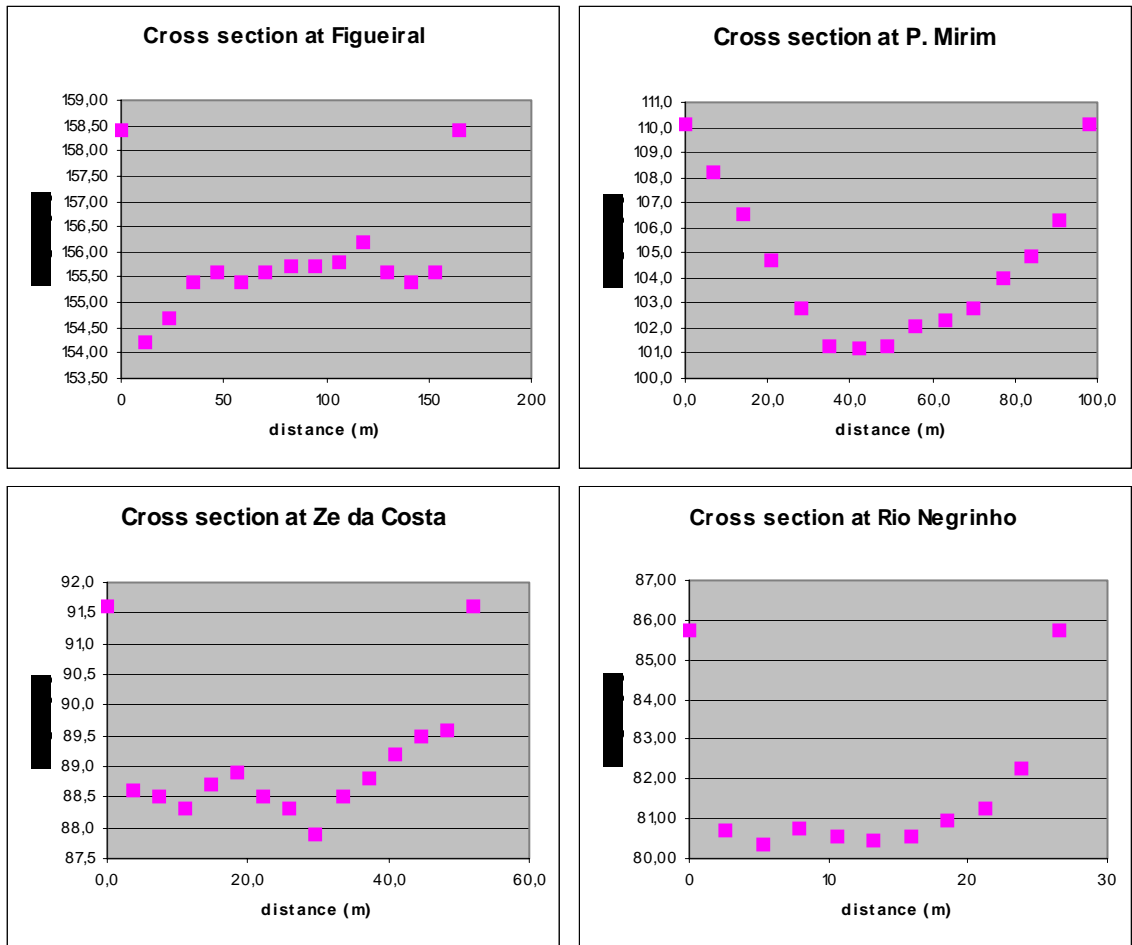
Figure 31 Cross-section at four locations obtained from measurements

The data from the PCBAP report are from the year 1995. The profiles for these cross-section locations are given in Figure 32 and in Figure 33. The figures show that the depth as well as the width is significantly different at various locations. The profile with the lowest number (TK3) is at the upper part of the river Taquari and the profile with the highest number (TK11) is at the lower end of the Taquari. The dimensions of the cross-sections are smaller at the lower end of the Taquari. This can be explained from the numerous distributaries that take off from the Taquari in the Pantanal.
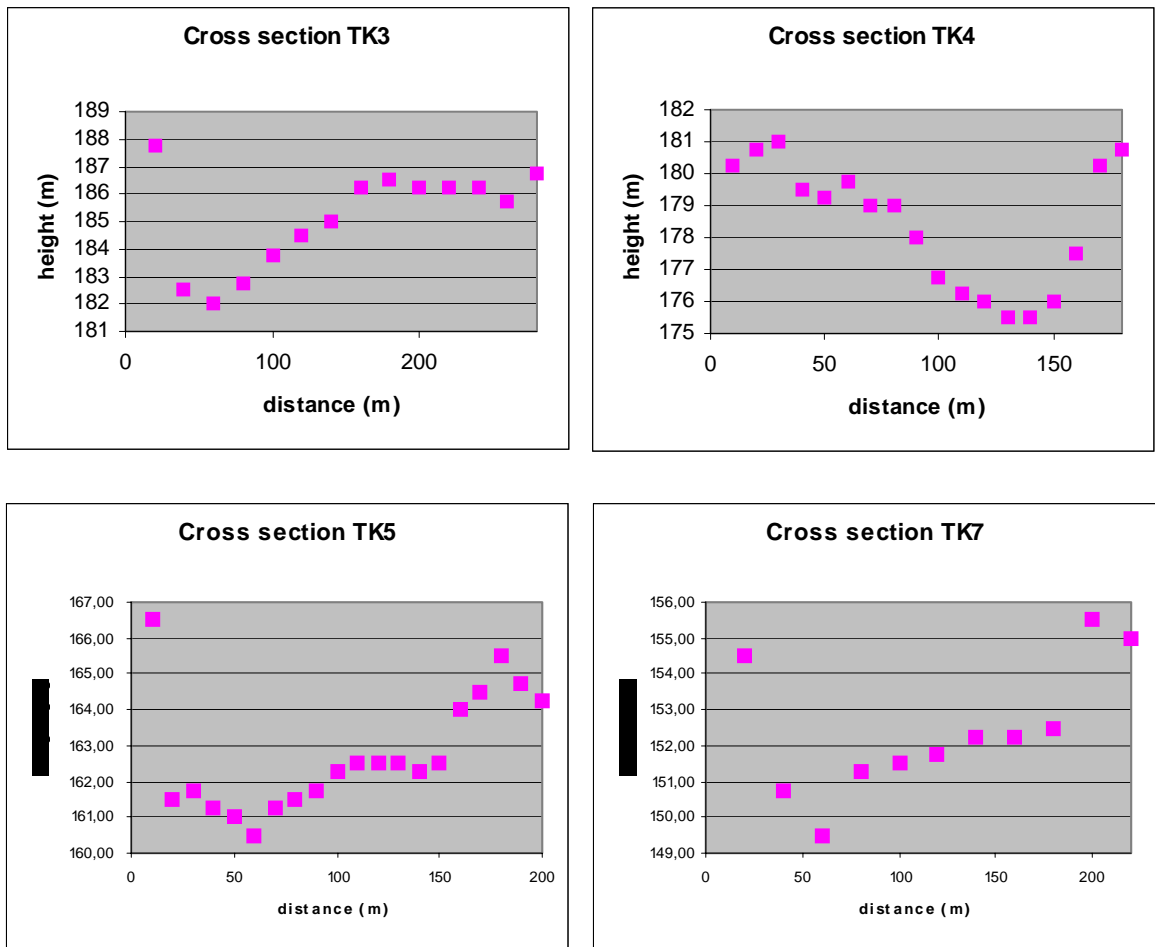
Figure 32 Cross-section for the upper river Taquari from PCBAP report

The cross-sections in Figure 32 are located upstream from the bifurcation at Caronal. The cross-sections TK8 and TK9 in Figure 33 are also located upstream from the avulsion. The cross-sections TK10 and TK11 are located downstream of the avulsion.
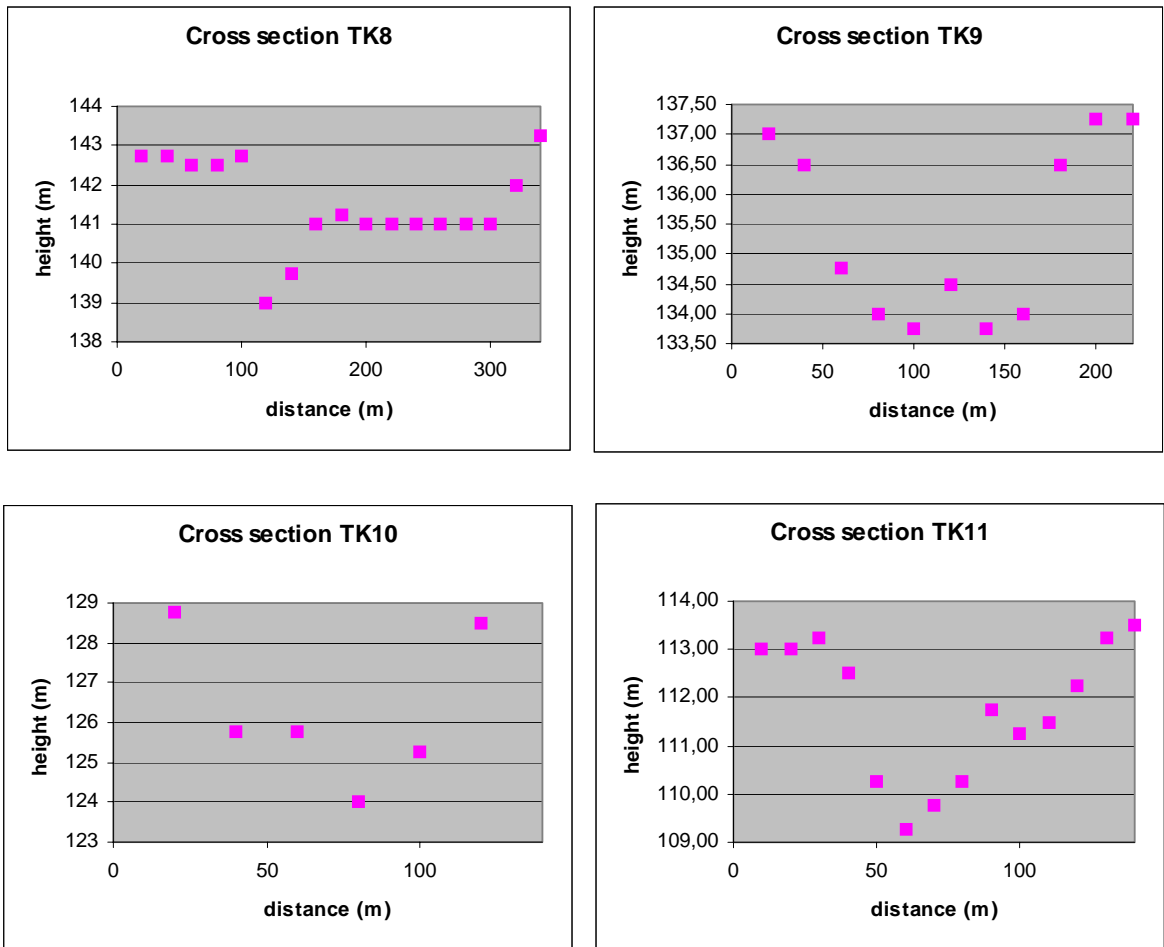
Cross section TK8

Cross section TK9

Cross section TK10

Cross section TK11

Figure 33 Cross-section for the upper and lower river Taquari from the PCBAP report

5.2 Rio Paraguai

Amolar is an upstream boundary location for the SOBEK model. Exactly at that point it is not possible to enter data for a cross-section in the SOBEK model, so a cross-section location was added just downstream of the upstream boundary at Amolar. For this cross-section location the data from the ANA database for Amolar on 27th of July 1999 were used. Figure 34 shows the data for the cross-section at Amolar.
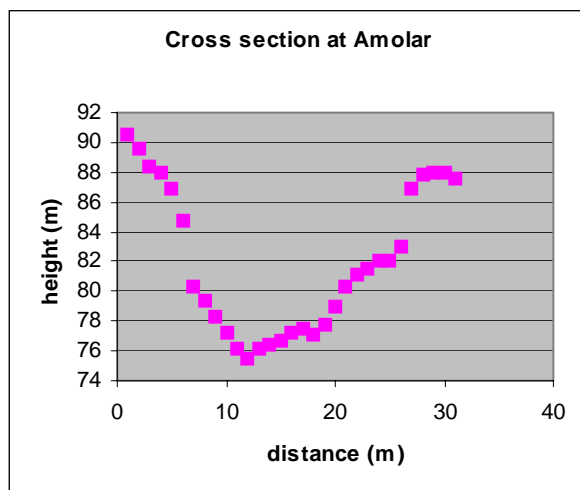
Cross section at Amolar

Figure 34 Cross-section for the river Paraguai at Amolar

Between Amolar and the lower boundary of the SOBEK model at Porto Esperança cross-sections are added to the schematisation for three other locations. These three locations are the Lodario, Sao Francisco and Porto da Manga stations. For the Lodario station no profiles were available so the data from Sao Francisco were used, because this was the most closely located station at the same river branch, with almost the same amount of discharge. Figure 35 presents the cross-section for the station Sao Francisco.
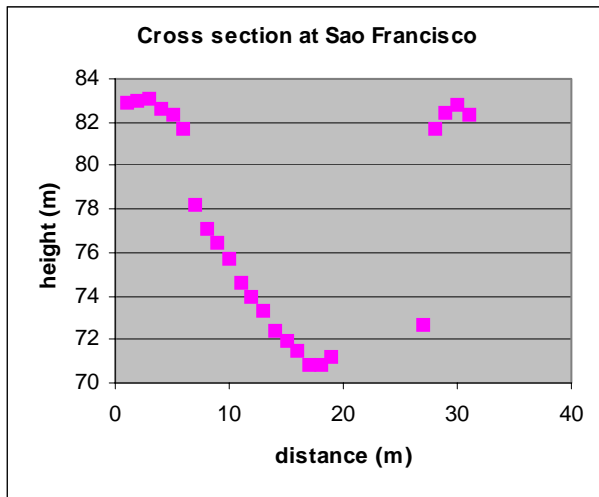

Figure 35 Cross-section for the river Paraguai at the station Sao Francisco

In Figure 36 the data for the station Porto da Manga are shown. These data were also used for Porto Esperança the station, because at this station no measurements were available.
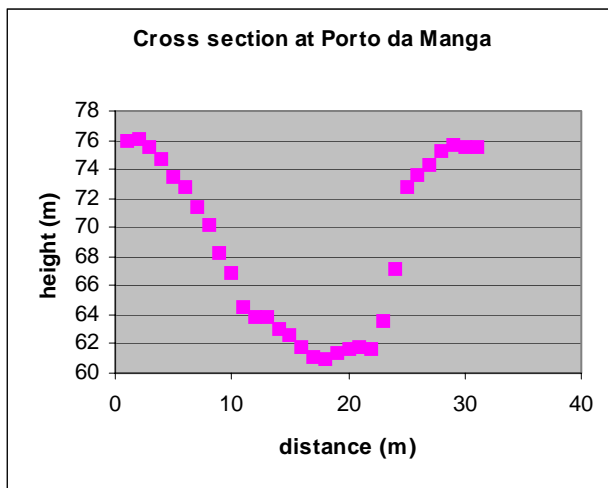

Figure 36 Cross-section for the river Paraguai at station Porto da Manga

6 Overview of data used in SOBEK model

This chapter gives an overview of the data used in the latest version of the SOBEK model and the data that have been prepared for use in the three scenarios and for calibrating the model. The river channels need input, which is specific for that channel. The first two paragraphs describe the input data used for the river Paraguai and the river Taquari. The last paragraph gives information on the parameters, which are applicable for the whole model.

6.1   River Paraguai

The following data were used for the river Paraguai:
- For the river Paraguai profiles from the ANA-database from the year 1999 were used (as described in Chapter 5).
- For all cross-section locations a hydraulic Nikuradse roughness of 0.003 m is defined for the river bottom and embankments
- Discharge data at Amolar extracted from the Hymos database for the period 01-10-1999 to 30-09-2000 were used
- Water level data at Porto Esperanca from the Hymos database for the period 01-10-1999 to 30-09-2000 were used
- A shapefile based on a recent satellite image with the exact location of the river Paraguai following the drainage pattern from the DEM
- For the 'wet', 'dry' and 'average' scenarios, discharge data at Amolar and water level data at Porto Esperanca were used.

6.2   River Taquari

The following data were used for the river Taquari:
- For the river Taquari profiles from the ANA-database (1999), from a PCBAP report (September 1995) and from fieldwork done by Carlos Padovani were used (see also Chapter 5). Locations of these profiles were given (in UTM coordinates or geographical coordinates (latitude/longitude))
- For all cross-section locations a hydraulic Nikuradse roughness of 0.003 m is defined for the river bottom and embankments
- Discharge data at Coxim extracted from the Hymos database for the period 01-10-1999 to 30-09-2000 were used
- The location of the river bifurcation at Caronal and profiles for this river bifurcation were estimated
- A shapefile based on a recent satellite image with the exact location of the river Taquari following the drainage pattern from the DEM. The eastern reach of the lower Taquari river was not used in the 1D model.
- For the 'wet', 'dry' and 'average' scenarios discharge data at Coxim were used.

6.3   2D part of model

In this section the input parameters, which will apply for the whole model, will be described. The following data was used for 1D2D model:

- The time step used for simulation is 30 minutes for the hydrological year 2000 (01-10-1999 to 30-09-2000)
- A series with precipitation and evaporation extracted from the Hymos database for the period 01-10-1999 to 30-09-2000 was inserted in the model.
- For the meteorological parameters wind, temperature and radiation the default values were used, because in this case they do not influence the results.
- The initial water level in 1D channels was set to 1 metre
- The method used for interpolating between successive cross-section locations is set to 'interpolation bank levels'
- The method used for calculating the flow of water from the 1D channel to the 2D grid is set to 'assume highest level of embankments'
- An initial infiltration capacity for the whole grid area is set to 5 cm
- GIS output for water levels, water depth and velocity is generated for every 30 days (more or less each month)
- A DEM with cell size 900 * 900 m was used (based on a 90 * 90 m grid created by ITC)
- A grid with hydraulic roughness values was used (based on a vegetation map created by Alterra)
- For the 'wet', 'dry' and 'average' scenarios, precipitation data and evaporation data were used.

6.3.1   Digital elevation model

Ben Maathuis from ITC created a digital elevation model from data from the SRTM 2000 mission. The digital elevation model was corrected for drainage and vegetation. The resolution from the resulting elevation model was 90 * 90 metre. For the first SOBEK model the resolution from this elevation model was too fine, resulting in a very long simulation time. Accordingly, using the mean elevation from each hundred grid cells, a coarser grid with a resolution of 900 * 900 metre was created. Figure 37 shows the digital elevation model with a resolution of 900 * 900 metre.
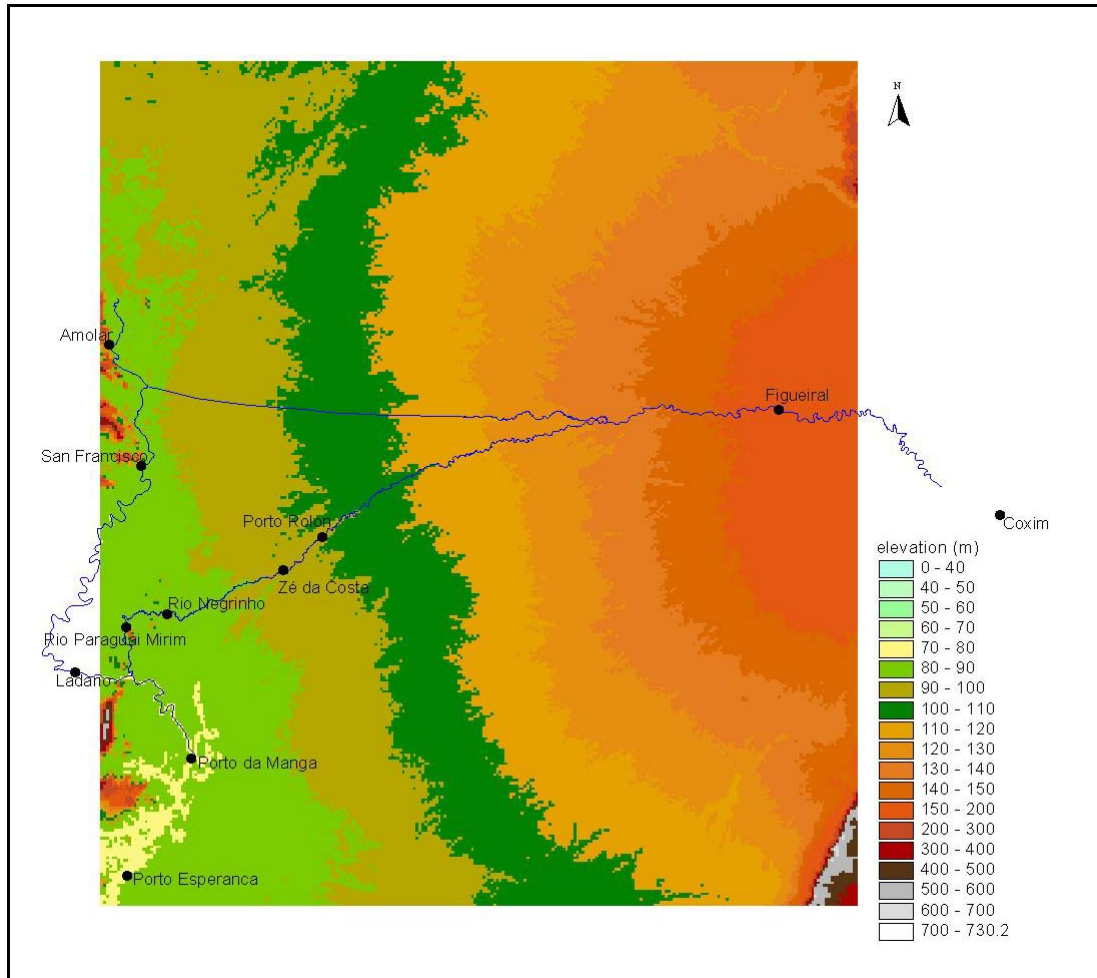
Figure 37 Digital elevation model used for 1D2D-model

6.3.2 Map with hydraulic roughness

The first grid with hydraulic roughness was based on a shapefile with vegetation types. The shapefile was classified into six different vegetation groups. Data from the satellite image from the dry period were put on top of the vegetation shapefile and a grid with a cell size of 900 * 900 m was created (see Figure 38).
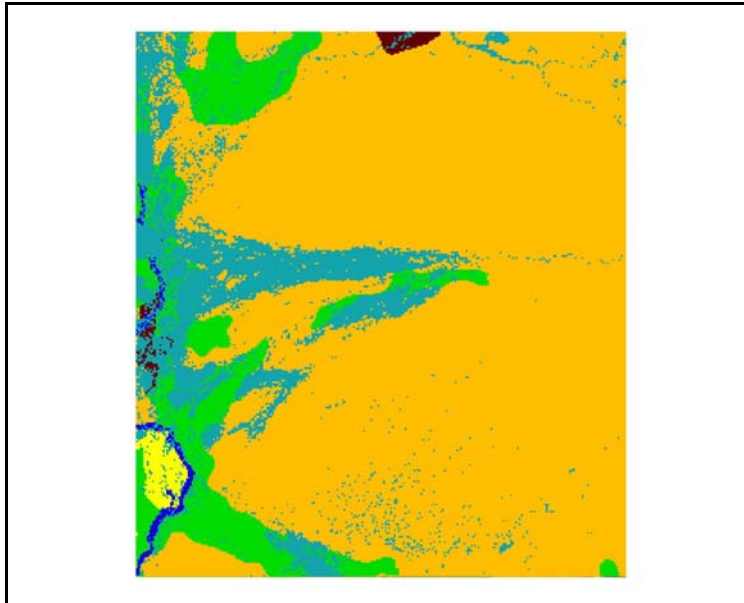
Figure 38 Grid with hydraulic roughness values; orange = 1m; dark blue = 0.003m; green = 1.5m; yellow = 0.4m; grey = 0.1m; dark brown = 5m and the value 4 is not on the map.

An improved vegetation map from Alterra was used in a later version of the model. This vegetation map had a resolution of 90 * 90 m. This improved vegetation map shows more spatial variation than the first vegetation map (see Figure 39). The spatial variation was necessary for improving the distribution of inundated areas (see Chapter 7).

The vegetation map was converted to a map with hydraulic roughness (Nikuradse-values) using the values as listed in Table 1. The roughness of the different vegetation types were derived form a handbook of hydraulic roughness for Dutch river systems. Pictures showing the different vegetation types have been compared with pictures of the vegetation in the Pantanal and similar roughness values have been used.

Table 1 Hydraulic roughness (Nikuradse) values for each vegetation type

no.	vegetation type	hydraulic roughness (m)	Handbook type (h = 1 m)
1	galery forest	7.0	zachthoutstruweel
2	(semi) decidual forest	7.0	zachthoutstruweel
3	form. pioneiras (transicao)	5.0	zachthoutstruweel
4	savana forested (cerradao)	6.0	doornstruweel
5	savana arboreal (cerrado)	3.0	droge ruigte + 10%
6	savana gramineo lenhosa	4.0	riet
7	savana gramineo lenhosa + arboreal	3.5	average of 5 and 6
8	pionier vegetation	1.5	homogene natte ruigte
9	area cultivada	0.8	verruigd grasland
10	baia	not present	
11	corixo	not present	
12	oxbow	not present	
13	salina	not present	
14	vazante	not present	
15	river	0.05	waterbodem (plas)
16	bare soil	not present	

Source: Stromingsweerstand vegetatie in uiterwaarden. Deel 1 handboek versie 1-2003. E.H. van Velzen, P. Jesse, P. Cornelissen and H. Coops. RIZA rapport 2003-028, Arnhem.
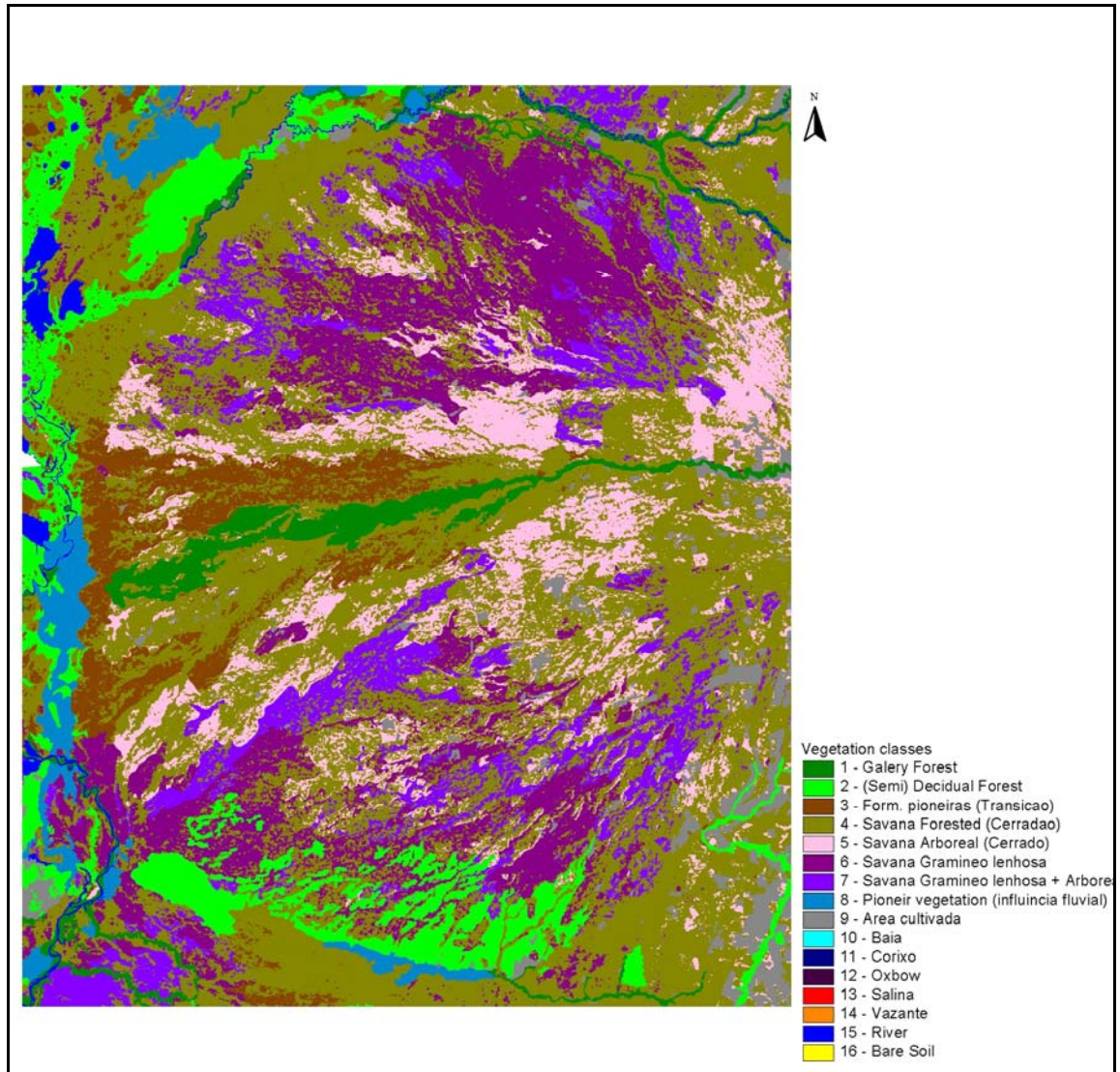
Figure 39 Improved vegetation map from Alterra

Thereafter the grid was aggregated to a grid with a resolution of 900 * 900 m using the median value. A comparison from three methods (median, mean and maximum) showed that the method with median values gave the most similar pattern with the original grid. The method using the median values resulted in the map with hydraulic roughness as shown in Figure 40.
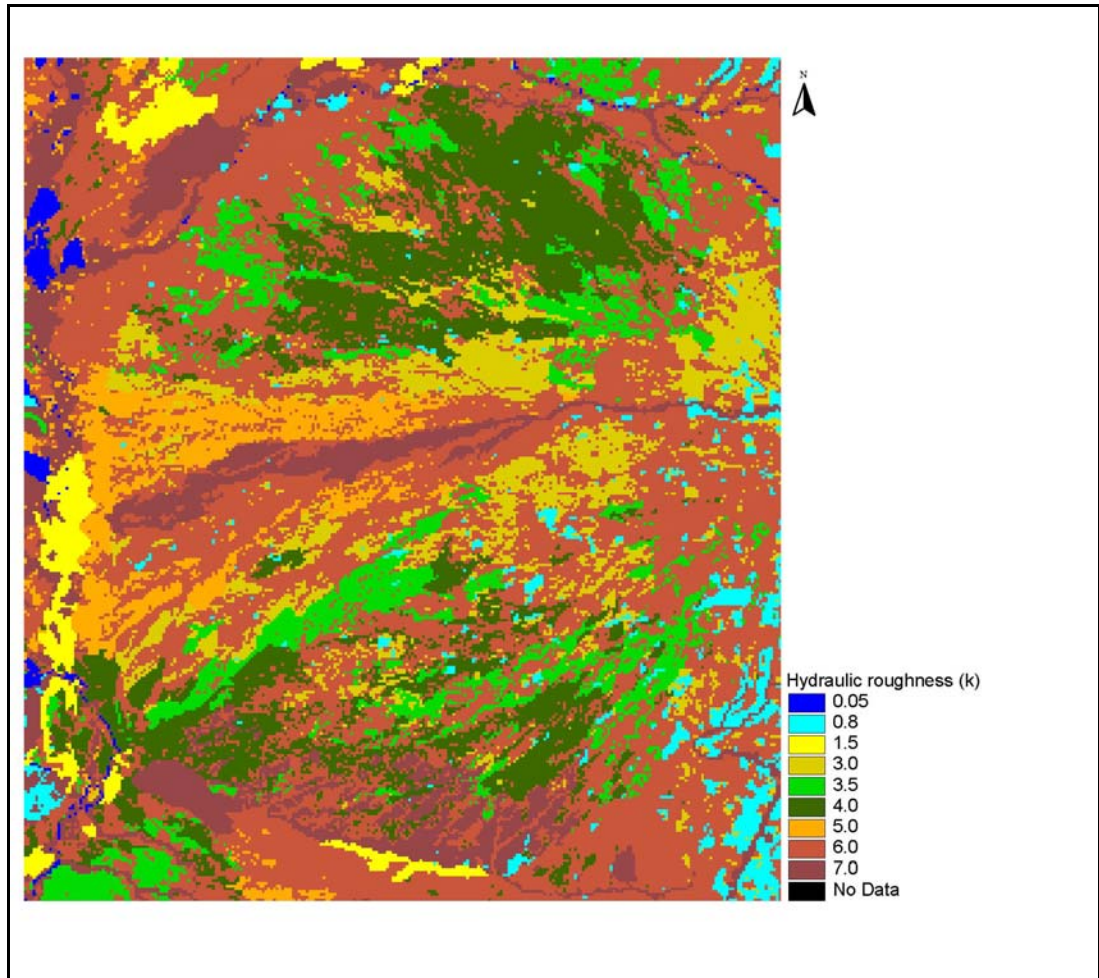
Figure 40 Map with hydraulic roughness values derived from improved vegetation map

7 Calibration

For the calibration of the SOBEK model data, for the hydrological year 2000 (01-10-1999 to 30-09-2000) have been used. SOBEK can be calibrated using many different parameters. For the calibration of the model it is common to use the parameters, which are the most uncertain. In this case it is hard to say which parameters are the most uncertain. The parameters hydraulic roughness and the infiltration capacity have been chosen based on experience with previous models.

The values used for the hydraulic roughness have been based on a handbook for vegetation roughness for Dutch river systems. The vegetation types described in this handbook are compared with the vegetation classes on the map of the Pantanal region, using photographs and descriptions. For each vegetation type the value for the hydraulic roughness can vary within a certain range, depending on, among other things, the depth of inundation, flow direction, season, age of vegetation and the variation within a vegetation type. Within the range for a certain vegetation type the values are changed during calibration. The spatial pattern of the vegetation types has not been changed.

The infiltration capacity of the soil is varied within the range possible for wetlands based on expert judgement. This parameter is spatially homogeneous. The range of the values used in the calibration is 1 to 15 centimetres.

Due to the current availability of data it was possible to calibrate the model in two ways:
• Calibrate (validate) on spatial distribution of flooded areas.
• Calibrate on the discharges at Porto Esperanca (the downstream boundary of the model)
Maps showing the spatial distribution of inundated areas were available for the dry as well as the wet season. These maps were derived from satellite data for the year 2003. The spatial pattern of these maps can be compared with the spatial pattern on the maps generated during the SOBEK calibration run at the same moment (see Figure 41). The input parameters can be changed in a way that the spatial pattern of the resulting inundation maps from SOBEK is similar to the maps derived from satellite data. An improved vegetation map with more spatial variation was used to change the pattern of the inundated areas, but the results were not promising, the spatial pattern of the inundations did not change sufficiently to improve the calibration.

Figure 41 shows the inundated areas derived from satellite data in red and the inundated areas from the SOBEK simulation in blue. The drainage pattern on both images are similar, but the image from the satellite shows much larger inundated areas especially in the middle of the image around the river Caronal and around the lower end of the Taquari and in the northwest side of the image. The water that causes the inundation along the Caronal and Taquari in the satellite image is directly drained to the main channel in the SOBEK-model and induces very high discharge peaks. Only two parameters can influence the way the water flows outside the river channels, the hydraulic roughness (vegetation types) and the elevation model. Changing the hydraulic roughness has some influences on the velocity of water flowing through the model, but in this case it cannot induce large inundations as shown on the satellite image. It is very well possible that using the drainage pattern to create

river channels in the elevation model and later on aggregating it to a 900 * 900 m grid caused the problem. The dimensions of the channels in the aggregated elevation model are too big. This results in fast draining of the area, which is not realistic.
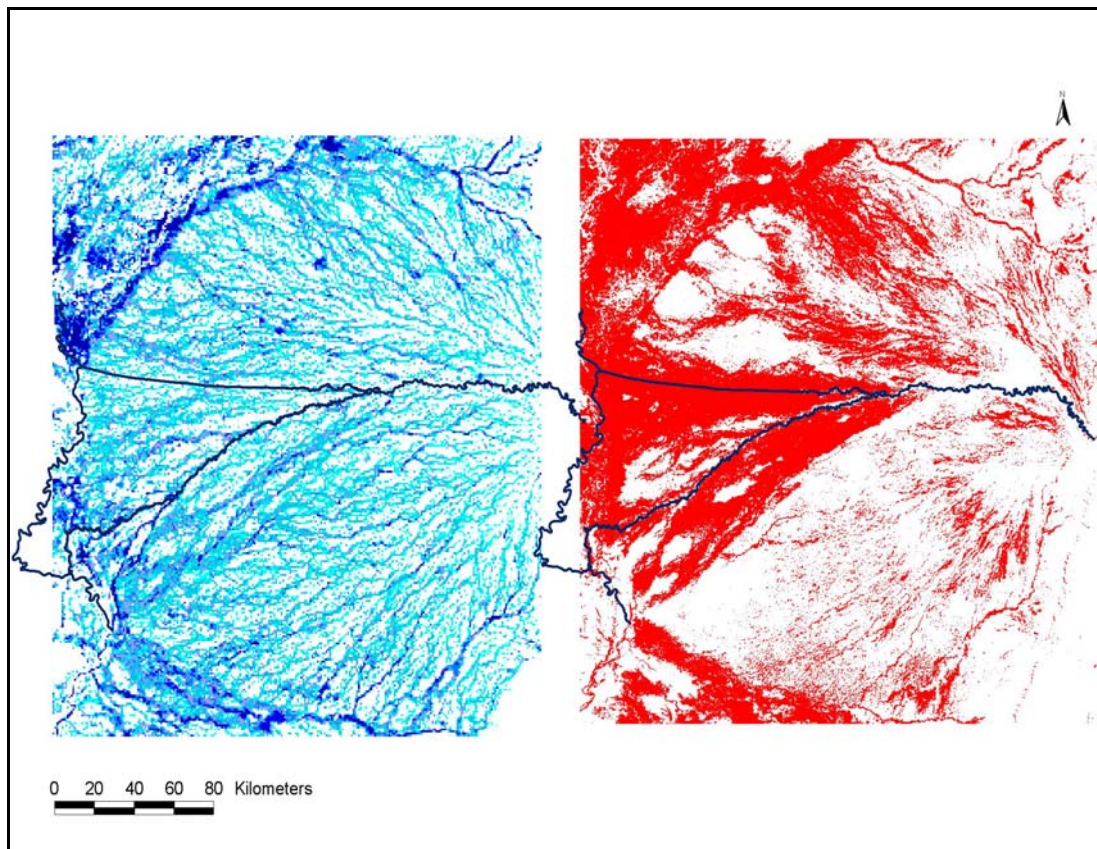

Figure 41 Comparison of simulated inundated areas from the calibration run (left) with satellite data from April 2003 (right)

The observed discharges at Porto Esperanca were obtained from the Hymos database. Observed discharges for the hydrological year 2000 were not available, so these discharges were created using the observed water levels of the hydrological year 2000 and the relation between discharge and water levels obtained from the historical dataset in Hymos. The 'observed' discharges are compared with the computed discharges at the branch just upstream of Porto Esperanca.

At first the discharge at Porto Esperanca was much too high and the peak of the discharge was in March instead of May or June. During the calibration process the infiltration capacity and the hydraulic roughness have been increased to decrease the amount of discharge and to delay the peak. Increasing the hydraulic roughness lowers the velocity of water flowing over the surface. As a consequence, the accumulation of water in the river channels will be delayed. Increasing the infiltration capacity will decrease the availability of water in the first months of the hydrological year, which is common in wetlands where at the start of the wet season the first amount of precipitation will infiltrate into the soil.

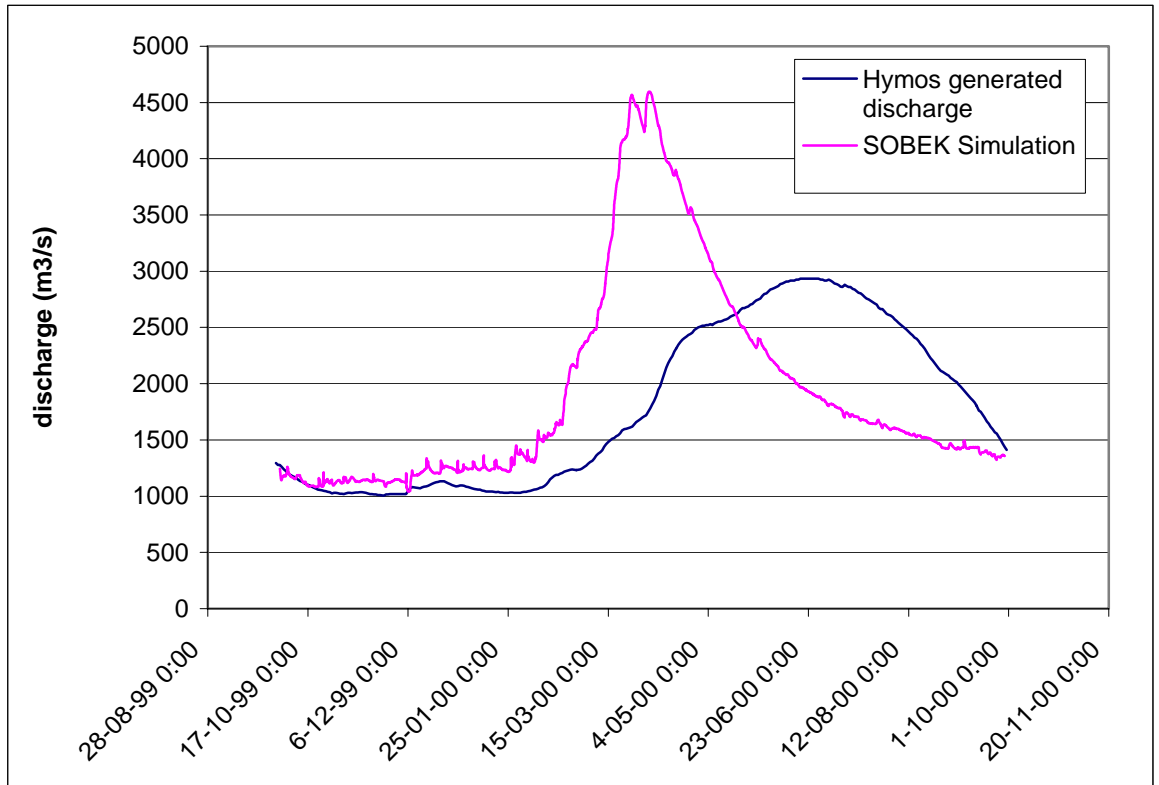 Figure 42 The simulated discharge with SOBEK and the generated discharge with Hymos
at   Porto
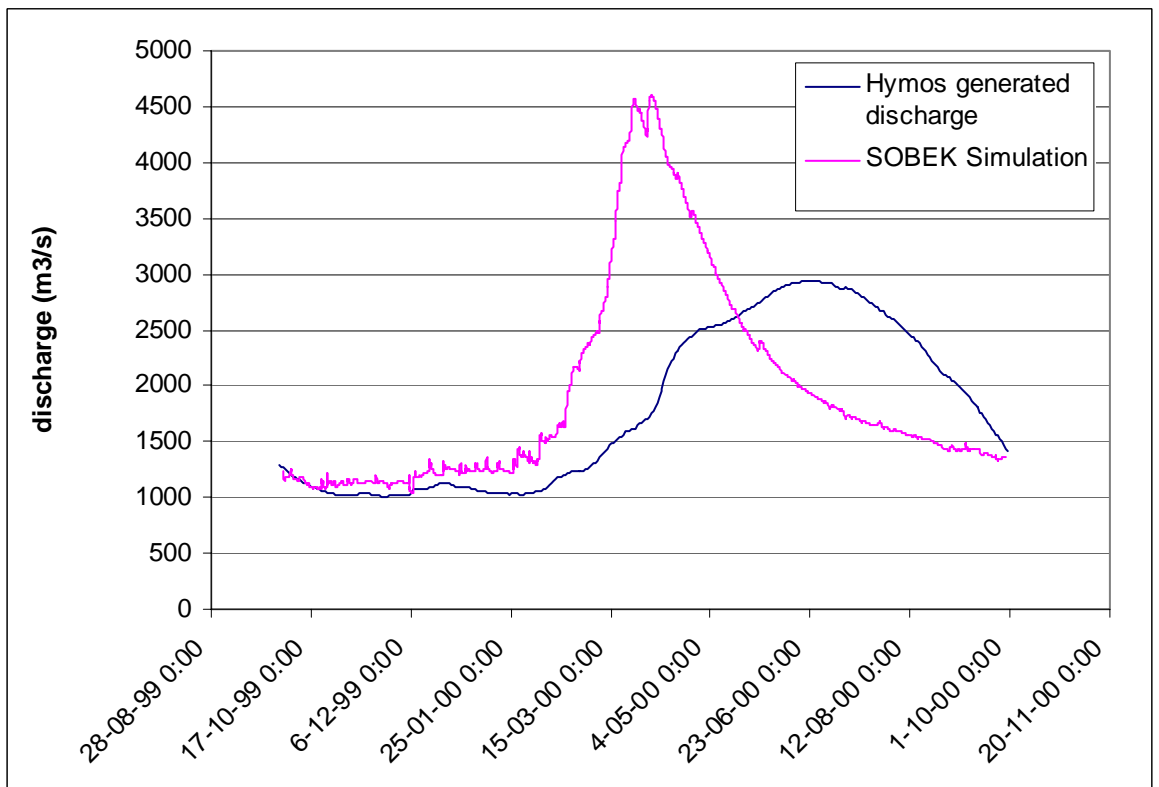Esperanca

 Figure 42 shows the still poor results of the calibration. The peak of the discharge is still too
high and it is in March instead of in May. Currently the water accumulates too fast in the

main channels. The travel time to these main channels should be longer. It is possible that in reality more water infiltrates in the bottom and drains to the river in the subsurface layer in which the flow velocities are much smaller. There are still more parameters that can be optimised and the current dimensions of the network can be changed, but therefore it is necessary to have more data on more locations to calibrate on.

8 Results of scenarios

Three scenarios were created to make three alternative runs with the SOBEK-model. These alternative runs will give an idea about the observed extremes based on a historical dataset that the natural system has to deal with. The scenarios are (as described in paragraph 3.3):

- 90% dry year
- average year
- 90% wet year

The 90% dry year is a hydrologically synthetical year in which for each time step 90% of the time steps at the same date in the historical dataset are wetter (in case of precipitation and discharge it means higher values). For the 90% wet year it means of course that 90% of the time steps at the same date are drier.
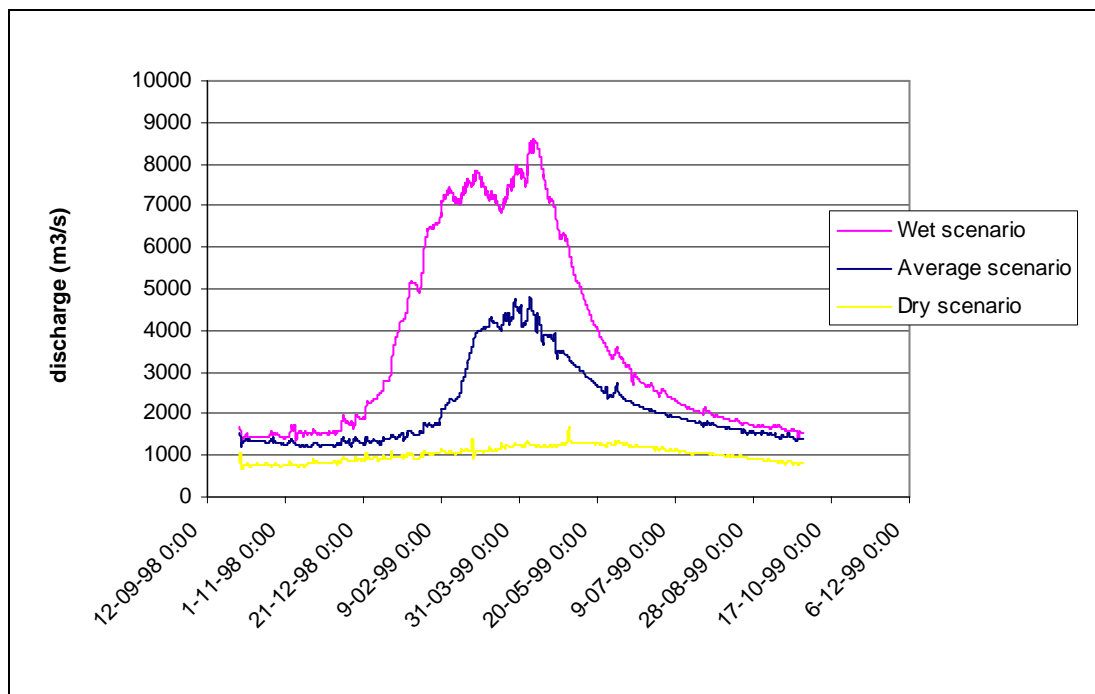

Figure 43 shows the simulated discharges for the three scenarios just upstream of Porto Esperanca. It is clear that the simulated discharges for the three scenarios show a large variation in the wet season. The discharges simulated in the wet scenario are higher than the highest observed value in the historical database. Further calibration with a more extended data set is necessary.
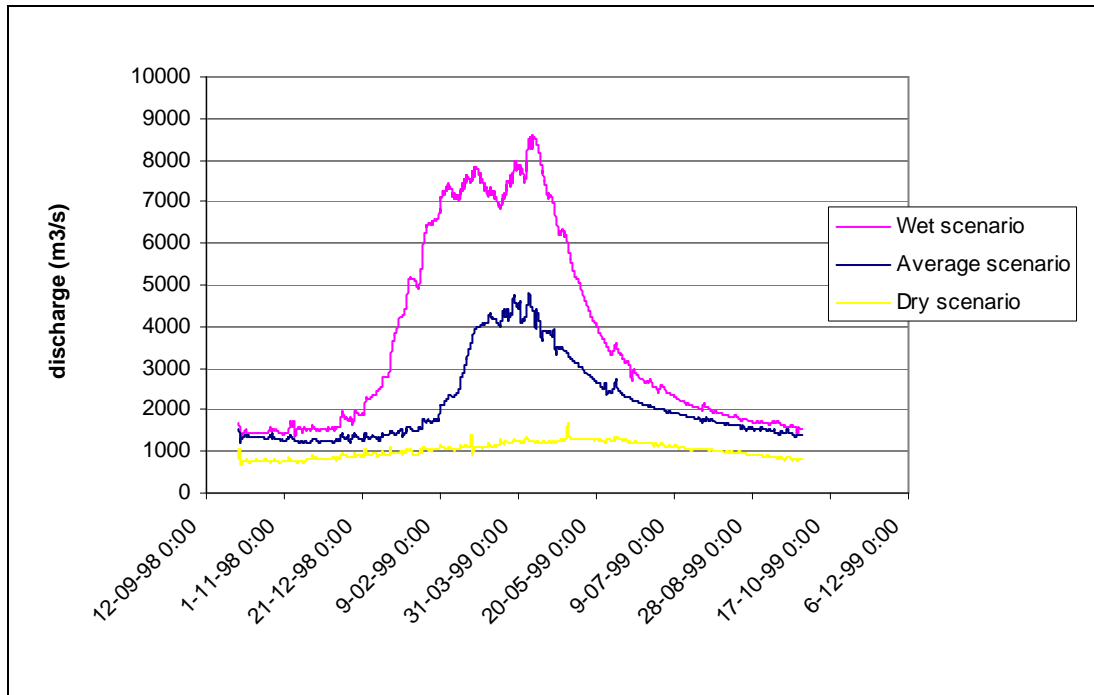
Figure 43 Discharge at Porto Esperanca for the three different scenarios

Maps of the inundated areas for the 27th of March (during the wet-season) in all the three scenarios are presented in Figure 44, Figure 45 and Figure 46.
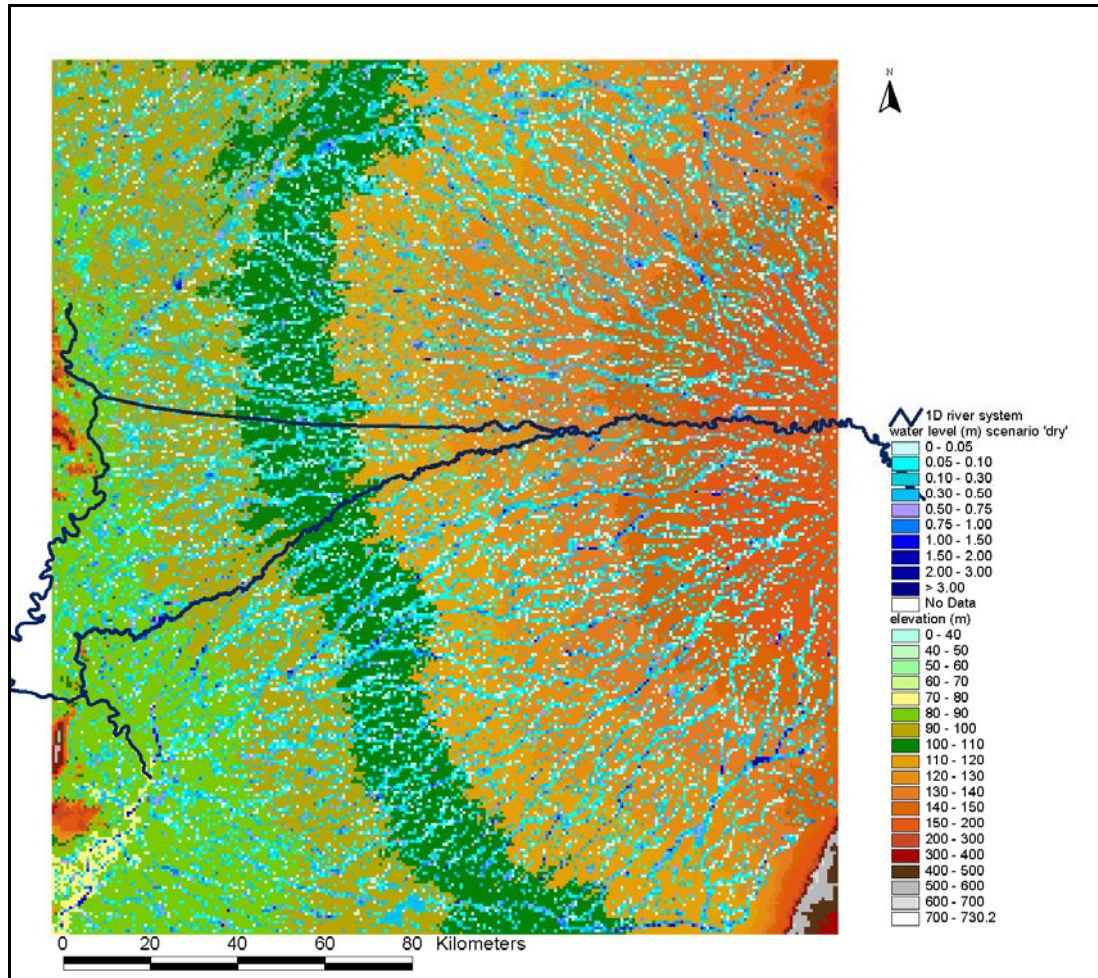
Figure 44 Simulated inundation areas for the 'dry' scenario

Figure 44 shows the map of the inundated areas in the 'dry' scenario. In this scenario there are almost no large inundated areas through the whole year. In this scenario the water accumulates in the smaller channels in the drainage pattern superimposed on the elevation model.
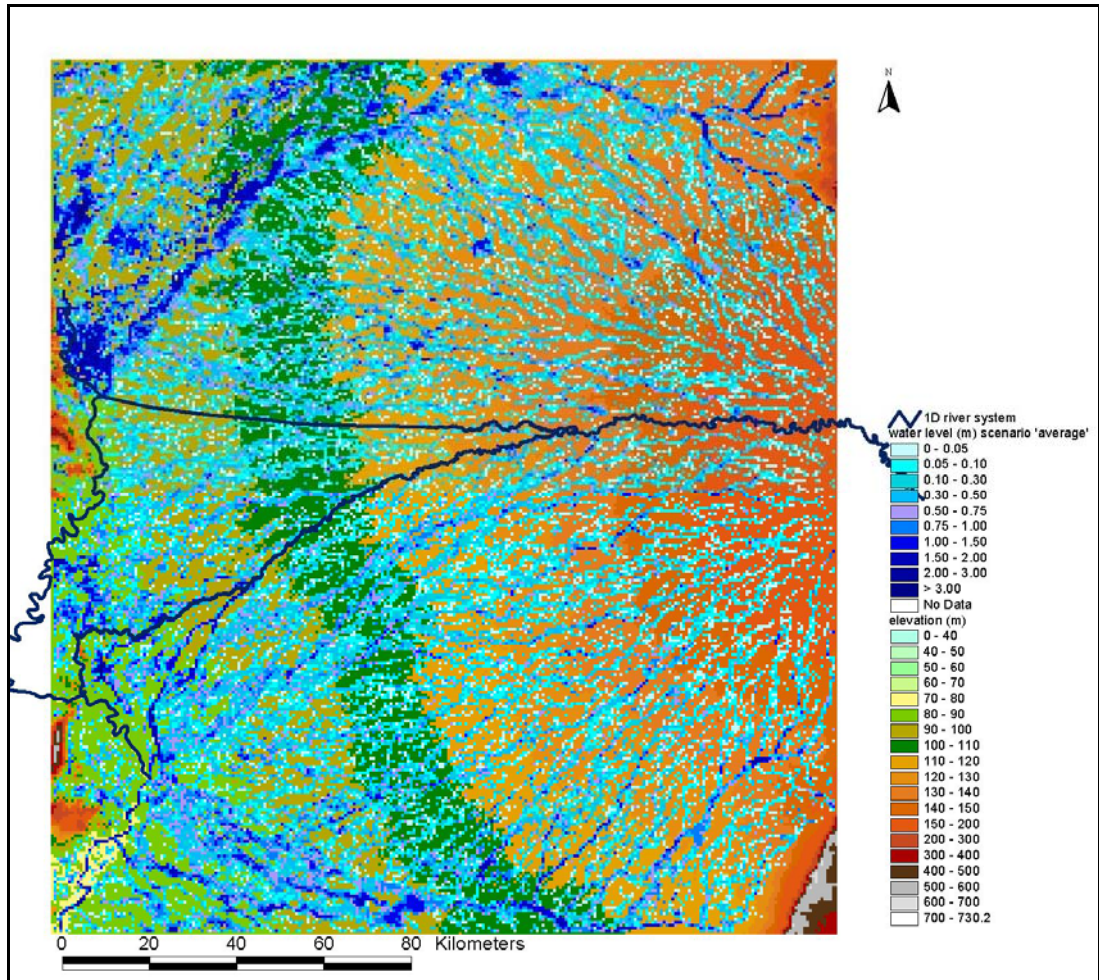
Figure 45 Simulated inundation areas for the 'average' scenario

Figure 45 shows the map of the inundated areas in the 'average' scenario. In this scenario more river channels have developed and some larger areas, mainly in the northwest and west side of the Pantanal, have been inundated. In the southern area a large river channel has been formed.
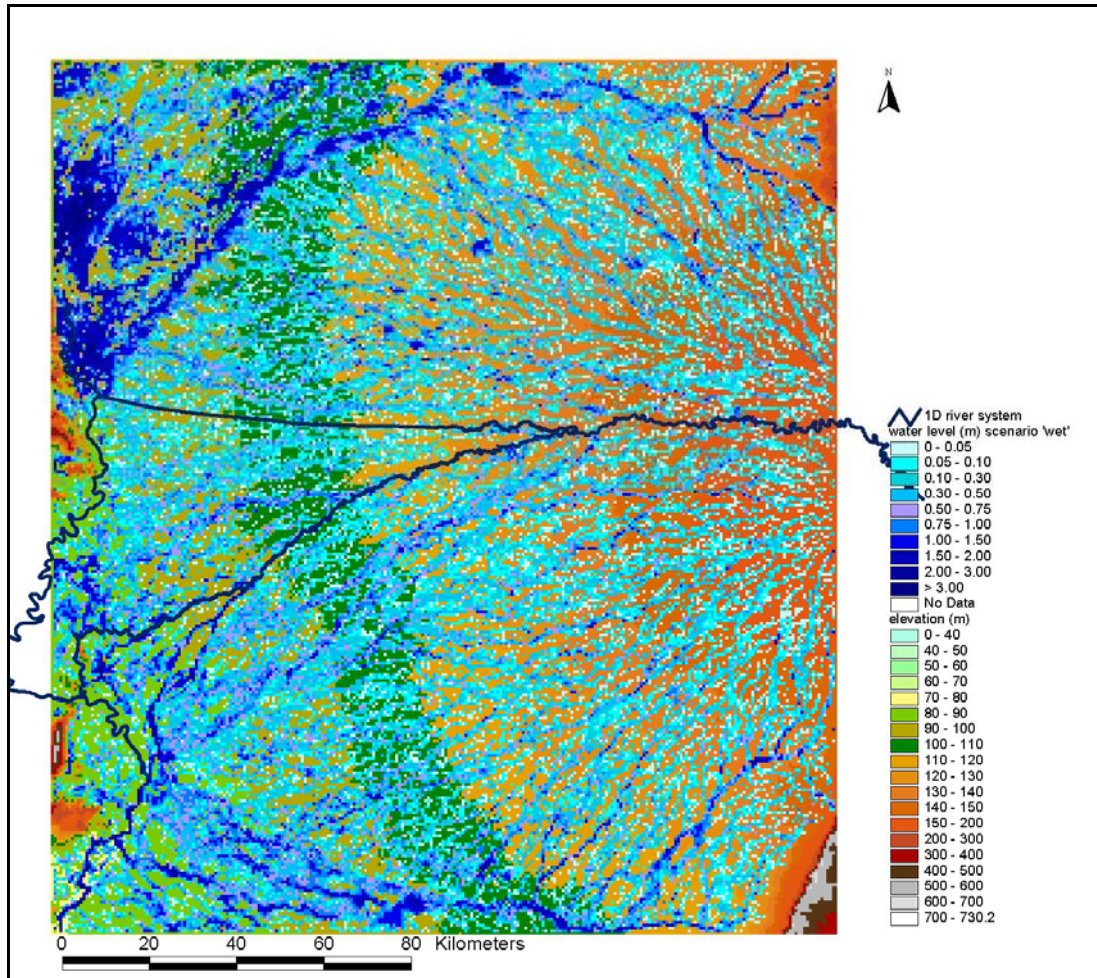
Figure 46 Simulated inundation areas for the 'wet' scenario

In Figure 46 the simulated inundated areas for the 'wet' scenario are presented. Compared with the other scenarios larger areas have been inundated. The water level in the inundated areas is higher and even more small river channels have been formed. But also in this scenario a large inundated area around the Caronal river, as can be seen on the satellite image, has not been formed.

9 Conclusions

The results of the hydro-meteorological data processing suggest that recent years are substantially wetter than the 1970s. The correctness of the data still needs to be ascertained, but the consistent similarity in trends from different hydrographic stations indicates that these trends cannot be explained from local errors. This is a potentially important result that will play a role in obtaining further insight in the functioning of the Pantanal and the problems experienced by the farmers in the area. Further in depth statistical analysis is recommended to substantiate this conclusion.

A combined one-dimensional and two-dimensional model has been set up in SOBEK. The computed spatial distribution of inundated areas resembles the distribution on satellite images, although there are still large differences, in particular in the north western and western zones of the model domain, where large inundated areas are not reproduced by SOBEK. Furthermore, the discharges are not reproduced well. Discharge peaks are too high and arrive too early (April instead of May-June). The discrepancies can be ascribed to two major causes:

1. The channels of the drainage patterns have become too wide or too deep during the pre-processing of the DEM by ITC. It is recommended to optimize this pre-processing on the basis of cross-sectional data and SOBEK model runs;

2. The spatial pattern of large inundated areas in the north western and western zones of the model domain depends sensitively on the topography and bathymetry of the area around the Caronal bifurcation. It is recommended to carry out a more detailed topographic and bathymetric survey in this area.

Nonetheless, the present model does provide insight in the extreme variations that the natural system has to deal with. This insight has been obtained by making computations for wet-year, ordinary-year end dry-year scenarios that had been derived from a historical dataset.

A   ExtrairDeHidro conversion tool

The ExtrairDeHidro conversion tool has been made specifically to allow data to be extracted from a Hidro database, as provided by ANA. The conversion tool has a single interface:

A.1   Using the tool
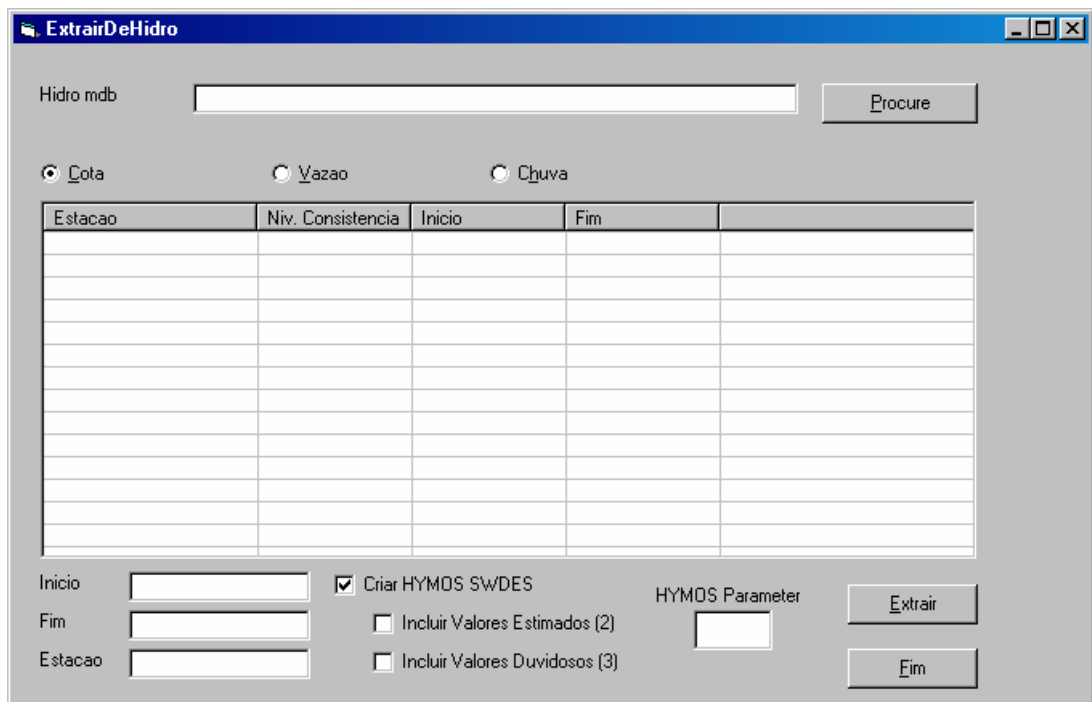
Step 1: Select a Hidro database and the Datatype required

- Click on Procure to select the required database. Alternatively press Alt-P

- Select the data type required:
    - Cota   :   Water levels
    - Vazao   :   Discharge
    - Chuva :   Precipitation

For the selected data type, the spreadsheet will show what records are available. When a database has been downloaded from the ANA website it will contain a single record only. When the database is an actual Hidro database, multiple records may be available.

Step 2: Select the required record

- Click on the required record to select it.

Records are distinguished by the following fields:

Field	Description
Estacao	ANA Station ID. In the HYMOS Pantanal database the same station ID's have been maintained. When a Hydrological and a Meteorological station coincide, the ID of the Hydrological station is used.
Niv. Consistencia	The Nivel de Consistencia is code for the level of validation of the data. Two possibilities exist: ● 1 Raw data, not verified ● 2 Validated data
Inicio	Start date of the series. The date indicates a month. The date is shown in the format of the computers Regional settings
Fim	End date of the series. The date indicates a month. The date is shown in the format of the computers Regional settings

By default the first record is selected.

Step 3: Change Station ID, Start or End date

After a record has been selected, the fields Estacao, Inicio and Fim in the bottom left of the window are filled with the Station ID, Start and End dates of the record. In these fields you can change the information.

When changing the Start or End date: make sure that you enter the date in the same format as the date shown. This is the date format of your computers Regional settings.

For Precipitation stations in the HYMOS Pantanal database it is often required to change the station ID. This is necessary for two reasons:

● The Meteo station ID in ANA start with a "0" (zero). In the database however, the ID is stored in a numeric field, which causes the leading zero to disappear. In ExtrairDeHidro you can enter the leading zero. This must be done, because the leading zero is used in the HYMOS database also. If the leading zero is not added, the data will not import.

● When a Meteorological station exists at the same location, only one location is created in HYMOS. The ID that is used is then the Hydrometric station ID. For example: Coxim. The rainfall data at Coxim are stored in Location Coxim, using ID 66870000, while in the ANA database these are stored under 01854004.

Step 4: Indicate if HYMOS SWDES file must be created

The conversion tool will always create a standard output file. A HYMOS SWDES file can also be created, this is optional.

If you have selected to create a HYMOS SWDES file, you can then indicate if estimated values and / or doubtful values should be exported also.

- Incluir Valores Estimados (2)
  If selected, the conversion tool will include all values that are flagged as being estimated in the SWDES file. If not, these values will be marked as missing in the SWDES file. The Hidro code for estimated values is '2'.

- Incluir Valores Duvidoses (3)
  If selected, the conversion tool will include all values that are flagged as being doubtful in the SWDES file. If not, these values will be marked as missing in the SWDES file. The Hidro code for doubtful values is '3'.

It is advised not to include estimated or doubtful values unless the method of estimation and ensuing accuracy is known to you. There are many options in HYMOS to carry out your own validation and following that fill the missing data. After doing so, the data will also be marked in HYMOS as estimated.

Step 5: Enter HYMOS Parameter code

If you have selected to create a HYMOS SWDES file, the HYMOS Parameter code is required. Enter the Parameter code as it has been set up in the HYMOS database into which the series will be imported.

Step 6: Extract the data

Extract the data by clicking on the Extract button. The conversion tool will read the data from the ANA database and create the selected output data files:

- A standard output file, formatted according to the regional settings of the system. This file is always created.

- An SWDES file for importing into HYMOS. Depending whether inconsistencies have been encountered in the database, an equidistant or Non-equidistant datafile is created.

A.2   Output files

Standard output file

The naming convention of the standard output file is as follows:

DataType_Nivel de Consistencia_Start date_End date.dat

DataType can be: Chuva, Cota or Vazao

Example:
Chuva_01857002_2_01-01-1968_01-12-2000.dat

Rainfall data for location 01857002, with 'Nivel de Consistencia = 2, starting on 01-01-1968 and ending 01-12-2000. The date format is the date format specified as 'short date' in the regional settings.

The standard output file has a very simple lay-out.
for each record the following is given:

Date; value, quality flag

separated by semi colons (;).

Example:
```
18-06-1968;  .00;  1
19-06-1968;  .00;  1
20-06-1968;  .00;  1
21-06-1968;  .40;  1
22-06-1968;  .00;  1
23-06-1968;  .00;  1
24-06-1968;  .00;  1
```

SWDES Equidistant and SWDES Non Equidistant files

A comprehensive description of these file types is given in the HYMOS manual.