Prepared for
Dutch Ministry of Public Works - Rijkswaterstaat
RIZA

A water balance model for the
Stentsovsko-Zebrijanske Plavny

Report
January 1998
A water balance model for the Stentsovsko-Zebrijanske Plavny

R. Fokkink
The Stentsovsko-Zebrijanske Plavny (Ноздороєвяч-Ілєаїїїїїїїїїїїїїїїїї) is a wetland in the Danube Delta which is a natural habitat for a great variety of wildlife. The wetland has a unique mosaic landscape of water and reed. Ecological experts of the Ukraine and the Netherlands have designed various water management options for the wetland, to improve its ecological value. In this report, these options are evaluated by simulations of the water balance model SZP-HYDRO.

This study contains a description of the data collected by the IBSS (Institute for Biology of the Southern Seas, ЕАНН, Odessa branch) during the field survey of 1997. These data were used to calibrate SZP-HYDRO. General data available from the IBSS and from the Hydrometeorological Institute at Izmail were processed into a synthetic dry year, average year and wet year. The management options were simulated for the average year.

The study presents the hydrological results of the water management, but it draws no conclusions on the ecological impact of the water management. This is left to the ecological experts.
Summary

The Stentsovsksko-Zebrijske Plavny is a wetland in the Danube Delta which is a natural habitat for a great variety of wildlife. The construction of the Sasik channel in 1980 has divided the Plavny into two parts, Stentsovsko to the west of the channel and Zebrijske to the east. This has changed the hydrodynamical conditions of the wetland because the channel has cut through natural channels in the wetland. At present, the growth of dense reed beds is progressing, which threatens the natural habitats. This problem is most urgent in the southern part of the Zebrijske Plavny.

Specialists of RIZA in the Netherlands and of DPA and IBSS in the Ukraine have studied which water management is most likely to improve the living conditions for the wild life in the Plavny. In a RIZA report (Iedema, 1997), three management options were identified. The first option is to increase the exchange volumes in the Plavny (‘marginal wetland scenario’). The second option is to increase the water levels by fresh water inlet (‘springflood riverrine scenario’). The third option is to increase the water levels by fresh water inlet and salt water inlet (‘springflood estuarine scenario’). These options are studied in the present report.

RIZA commissioned DELFT HYDRAULICS to build a mathematical model of the water balance in the Plavny to evaluate the management options. During a two week visit of DELFT HYDRAULICS to the Ukraine the water balance model SZP HYDRO was developed. The model results show that the management has a great effect on the hydrology of the Plavny. Both the exchange volumes and the water levels in the Plavny can be increased significantly. All three management options have the desired effect and it is up to the ecological experts to decide which option is most suitable.

The Stentsovsksko Plavny and the Zebrijske Plavny are separated by the Sasik channel. The model results show that the siphon under the Sasik channel is a bottleneck. The siphon never reaches its maximal capacity, because the outflow through the Zebrijske Plavny is hampered by dense reed beds. Therefore the water exchange between the Stentsovsksko Plavny and the Zebrijske Plavny is limited and this is probably the reason why the southern part of the Zebrijske Plavny deteriorates. The flow through the siphon can be increased by dredging the main channels in the Zebrijske Plavny.

The ecological interpretation of the model results has to be based on water levels and exchange volumes between the Plavny. Information on the exchange between the open water and the reed beds would also be valuable. This exchange is incorporated in the model, but it has not been calibrated yet. It would be possible to calibrate this part of the model by means of a salt balance. At present there is not sufficient data on the salinity in the Plavny to carry out such a calibration.
Acknowledgements

Discussions with various experts have been helpful to improve the understanding of the Plavny. In particular, the discussions with Dr. Alexandrov, Dr. Voloskevich and Dr. Zhmud were brief but instructive.

The results in this report were obtained in co-operation with Mr. V. Egorashenko whose long year knowledge of the hydrology of the Plavny has been very valuable. Michail and Elena Zhmud are thanked for their hospitality during the field trip to the Plavny. The IBSS, and Nikolai Berlinsky in particular, provided excellent accomodations in Odessa at very short notice.
Содержание

Стенцовско-Жебрияновские Плавни - это болотистая местность в дельте Дуная, которая является природной средой обитания разнообразных видов диких животных. В результате постройки Сасик канала в 1980 году Плавни были разделены на две части: Стенцовское к западу от канала и Жебрияновское к востоку от канала. Это изменило гидродинамические условия на местности, потому как канал пересек природные каналы. В настоящий момент из-за быстро разрастающихся плотных зарослей тростника природные условия местности подвегаются опасности. Наиболее остро стоит проблема в южной части Жебрияновских Плавней.

Специалисты RIZA в Голландии, а также ДПА и ИБСС на Украине изучили какие работы по управлению водным хозяйством должны быть проведены для улучшения условий дикой природы в Плавнях. В докладе RIZA (Iedema, 1997) были предложены три альтернативы. Первой альтернативой является увеличение объема обмена воды в Плавнях ("маргинальный сценарий"). Второй альтернативой является увеличение уровней воды посредством притока пресной воды ("сценарий речного оттока"). Третий альтернативой является увеличение уровней воды посредством притока как пресной, так и соленой воды ("сценарий лиманного оттока"). Эти альтернативы рассмотрены в настоящем документе.

RIZA поручила Delft Hydraulics создать математическую модель водного баланса в Плавнях для оценки возможностей управления водным хозяйством. Во время двух недельного визита Delft Hydraulics на Украину была разработана подобная модель SZP Hydro. Результаты модели показывают, что управление водным хозяйством имеет большое значение для гидрологии в Плавнях. Как объемы воды, так и уровень воды в Плавнях могут быть существенно увеличены. Все три альтернативы дают в конечном итоге желаемый результат. Экспертами по экологии должно быть решено какая из альтернатив является наиболее приемлемой.

Стенцовские Плавни и Жебрияновские Плавни разделены Сасик каналом. Результаты модели показывают, что сифон под Сасик каналом представляет из себя главную проблему. Сифон никогда не достигает своей максимальной мощности, потому-что отток через Жебрияновские Плавни затруднен из-за густых зарослей тростника. В следствии этого обмен воды между Стенцовскими Плавнями и Жебрияновскими Плавнями ограничен, и это вероятно является причиной ухудшения состояния южной части Жебрияновских Плавней. Поток через сифон может быть увеличен путем очищения дна главных каналов в Жебрияновских Плавнях.

Экологическая интерпретация результатов модели должна быть основана на уровнях и объемах обмена воды в Плавнях. Ценной является информация относительно обмена между открытой водой и водой в тростниковых зарослях. Этот обмен учитывается в модели, однако точно это еще не определено. Возможным является калибровка этой части модели посредством солевого баланса. В настоящий момент не имеется еще достаточного количества данных по солености в Плавнях для выполнения подобной калибровки.
Выражение благодарности

Дискуссии с различными экспертами были очень важны для улучшения понимания ситуации в Плавнях. В особенности короткие дискуссии с доктором Александровым, доктором Волошкевичем и доктором Жмад были полезными. Результаты этого отчета были получены совместно с господином В. Егорашенко, чей многолетний опыт по гидрологии в Плавнях был очень ценен. Особая благодарность Михаилу и Елене Жмад за их гостеприимство во время поездки в Плавни. ИБСС и в частности Николай Берлинский предоставили отличное жилье Одессе за короткое время.
1 Introduction

DELFT HYDRAULICS has prepared a water balance model SZP-HYDRO of the Stentsovsko-Zebrijanske Plavny. The purpose of the model is to support ecological experts in their design of management plans for the Plavny.

The water balance model SZP HYDRO has been developed in commission of the Dutch Fresh Water Management Authorities, RIZA. Various experts of RIZA have visited the area in the last few years to study the present situation and to develop management plans in cooperation with the Danube Plavny Reserve (DPA) and the Institute for Biology of the Southern Seas (IBSS). An overview of these plans was presented in (Van der Vat, 1997), which contains considerations of the hydrological and the water quality aspects. This report served as the basic reference material for the present study.

The water balance model has been filled with data collected by Mr. V. Egorashenko of the Southern Ukrainian Water Management Department, in commission of the IBSS. The water balance model has been calibrated and several water management options proposed by RIZA have been evaluated. This evaluation has not yet been carried out in detail as there is more data of the IBSS, which still needs to be processed. In particular, it will be used to prepare wet years and dry years for worst case scenario’s.

1.1 Contents of this report

This report contains the first findings of the model. It has been prepared during the mission of 29 March - 12 April. The results are still fresh and although the conclusions are there, the motivations have not always been worked out in detail.

The Plavny is described in a nutshell in chapter 2. The data of the field survey as well as some additional data is exhibited in chapters 3 and 4. The calibration of the water balance model, which allow some of the main conclusions on the hydrodynamics in the Plavny, is contained in chapter 5. Chapter 6 contains the model results for various management options. The conclusions are contained in Chapter 7.
2 Description of the Plavny

The Danube Delta is one of the largest and most significant European wetland areas with a unique complex of biotopes and a high species diversity. Situated at the intersection of the European bird migration roads, it constitutes a feeding and resting area for a large variety of birds. The Danube bifurcates into three branches, of which the Kilya branch in the Ukrainian part of the delta is the most water abounding. Since the river transports a considerable suspended load, the Kilya delta continuously progresses into the Black Sea.

Figure 1a Topographic map of the Kilya branch of the delta. The hatched parts represent areas of ecological interest.

Figure 1b Sketch of the Stentsovsko-Zebrijanske Plavny
The Stentsovsko-Zebrijanske Plavny is a wetland of approximately 75 km² which extends along the northern part of the Kilya branch. It is a mosaic landscape of open water and reed beds, which hosts a large variety of mammals, reptiles, amphibians and fishes.

### 2.1 Historical overview

The Plavny is located in a fertile area which is used mainly for agriculture. A large system of irrigation works leads water from the River Danube to the agricultural areas and pumps drainage water back into the Plavny. There are dams and channels around the Plavny which have been constructed for irrigation and for protection against river floods. The dam between the Plavny and the Zebrijanske Bay has been constructed in the beginning of the century. The two locks in the dam were built around 1965. Up to that date there was an open connection between the Plavny and the Zebrijanske Bay. The Mezcolhozny channel was also constructed in 1965.

The construction of the Sasik channel in 1980 has divided the Plavny into two parts. The western part is the Stentsovsko Plavny and the eastern part is the Zebrijanske Plavny, which are connected only by a siphon under the channel. The Sasik channel has cut through the natural channels in the wetland, which transported Danube water to the sea.

The major problem in the Plavny, and especially in the Zebrijanske part, is the decrease of the mosaic reed-water landscape and the increase of dense reed stands, which are less favourable for birds. The stagnation of water in the reed stands and the high quantities of dead organic material from the reed beds cause oxygen deficiency. This is a threat to the fish and frog population in the Plavny.

### 2.2 The hydrology of the Plavny

Figure 2 presents a map of the Stentsovsko-Zebrijanske Plavny with all the hydraulic structures. The gross direction of the water flow is west-east, from Danube to Black Sea, regulated by structures. The water enters the Stentsovsko Plavny from the Mezcolhozny channel through the Tupikovy lock, goes through siphon 1 into the Zebrijanske Plavny, and leaves the Zebrijanske Plavny through locks 4 and 5.
Figure 2 The hydraulic structures in the Stentsovsko-Zebrijanske Plavny

There are a few interior lakes in the Plavny, of which the Lake Dzebrijanovsky is by far the largest. It covers the main part of the open water in the Zebrijanske Plavny.

All locks are operated by personnel of the Danube Management of Structures, Lakes and Channels, from the branches in Kylia and Vilkovo. The personnel are instructed by the DPA.

The Tupikovy lock is located half way the Mezcolhozny channel. The Mezcolhozny channel is connected to the River Danube by the Mezcolhozny lock. The main purpose of the Mezcolhozny channel is to transport water from the River Danube to the agricultural area for irrigation, north of the Stentsovsko-Zebrijanske Plavny. There is a pumping station at the end of the Mezcolhozny channel. Under normal conditions the water level in the Mezcolhozny channel is kept at the same level as the level in the River Danube. If the level of the Danube is too high, the lock is closed to prevent the Mezcolhozny channel from flooding. The Tupikovy lock is of secondary importance to the irrigation authorities. The lock is opened if the water level in the Mezcolhozny channel is too high for the pumping station.

Siphon 1 is always open and there is a constant flow from the Stentsovsko Plavny to the Zebrijanske Plavny, because the water level is higher in the Stentsovsko Plavny. There are shutters to close the siphon, but they have never been used. Occasionally the siphon is cleaned to enhance the flow and this was done recently in December 1997. There is a second siphon, siphon 2, which connects the Stentsovsko Plavny to the Sasik channel. The flow through siphon 2 is not as large as through siphon 1, but nevertheless it is consistent.

Lock 4 and 5 connect the Zebrijanske Plavny to the Black Sea. Until recently these locks were only partially open. In September 1997 the locks were opened as far as possible, lowering the water level in the Zebrijanske Plavny. Both locks have two shutters of which one shutter is broken.
The broken shutters are jammed and they were closed until January 1998 when they were forced open on the instruction of the DPA. To this date the locks are opened fully.

The locks are operated now and then by unauthorised personnel, mainly recreational fishermen. One of the three shutters in the Tupikovy lock is jammed, it is constantly closed.

Besides the inlet of Danube water and the outlet of water to the Black Sea, precipitation and evapotranspiration are the main other sources of inflow and outflow. The evapotranspiration exceeds the precipitation, which indeed is the reason for all the irrigation works in the agricultural area.

There are six pumping stations which pump water from the agricultural area into the northern part of the Stentsovsko Plavny. This water has a relatively high salinity. There is one pumping station which pumps water from the fish ponds into the Zebrijanske Plavny.

The other sources of inflow and outflow are only minor. There is infiltration through the dams along the Sasik channel and the Black Sea. There may be upwelling from the River Danube to the Zebrijanske Plavny as indicated in (Van der Vat, 1997).
3 Hydraulic measurements of the field survey of 1997

The hydrological characteristics of the Plavny were measured by Mr. V. Egorashenko in commission of the IBSS in 1997 from April 1 to November 30. This data was used in the present study to examine the hydrology of the area and to calibrate the water balance model. An overview of the monthly data of the survey is given in a report of the IBSS (Egorashenko, 1998), which contains a water balance of the Plavny. The hydraulic measurements of the locks and the siphons in the Plavny are not contained in that report and have been processed by Delft HYDRAULICS in the present study.

3.1 Measurements of the structures

The locks in the Plavny all are the same type of weirs, containing two or three shutters, which are operated manually. Once or twice every month, the position of the shutter is varied by the operator of the locks. The position of the shutters is also varied by unauthorised people. The height of the shutter can easily be changed for the Tupikový lock, but this is more difficult for Lock 4 and 5.

The characteristics of the hydraulic structures have been measured by Egorashenko during the survey of 1997. The measurements were made for the position of the shutters at the time of the field trips. For some locks the shutter position was varied more than for others. For instance, the Tupikový lock was closed for 3 out of 5 of the field trips. Lock 4 and 5 were open, at least partly, for all the measurements.

The mathematical equation for a discharge \( Q \) through a weir is:

\[
Q = mA\sqrt{2g\Delta h}
\]  

\( m \) = discharge coefficient  
\( A \) = opening area of the shutter  
\( g \) = gravitational acceleration  
\( \Delta h \) = level difference before and after the weir

The equation for the discharge through the siphon is the same, with the only difference that the opening area \( A \) cannot be varied. Egorashenko has measured the flow velocity through the weirs and the siphon, using a mechanical velocity meter, for various cross sections at both sides of the weirs. He has estimated the discharge from this by estimating the cross section area. In this way he has calculated the discharge coefficients \( m \) for all shutters. Detailed information on these measurements is contained in (Egorashenko, 1998).
The measurements of Egorashenko were processed as shown in Figure 4. The measured discharge was compared to the measured \( A\sqrt{\frac{2g \Delta h}{2}} \) and the average discharge coefficient \( m \) was obtained by linear regression.

![Figure 4](image)

Figure 4 The discharge coefficient for lock 4 and lock 5

The deviation between measurement and regression is larger for Lock 4, but seems to be due to accuracy restrictions on the measurements since there is a scatter around the trend line. The coefficients and the size of the weirs are presented in Table 1.

Table 1 The current size of the weirs (total width not including the shutters that are permanently closed)

<table>
<thead>
<tr>
<th>Weir</th>
<th>no. shutters</th>
<th>no. working shutters</th>
<th>discharge coeff. m</th>
<th>total width*</th>
<th>maximal opening height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tupikov lock</td>
<td>3</td>
<td>2</td>
<td>0.60</td>
<td>4 m</td>
<td>1.5 m</td>
</tr>
<tr>
<td>lock 4</td>
<td>2</td>
<td>1</td>
<td>0.55</td>
<td>2 m</td>
<td>1.5 m</td>
</tr>
<tr>
<td>lock 5</td>
<td>2</td>
<td>1</td>
<td>0.51</td>
<td>2 m</td>
<td>1.5 m</td>
</tr>
</tbody>
</table>

Egorashenko has also measured the percolation through the shutters which are jammed. It is not possible to derive discharge coefficients from these measurements as the shutter opening \( A \) can hardly be determined. The measurements show that the percolation is 10 to 100 times as small as the average discharge through the weirs.

For siphon 2 \( \Delta h \) in equation 1 represents the level difference between the Stentsovsko Plavny and the Sasik channel. During the field trips the levels in the Sasik channel were not measured, so \( \Delta h \) had to be estimated from the average level in the Sasik channel. The size of the siphons and the measured discharge coefficients are shown in Table 2.
Table 2 The current size of the siphons

<table>
<thead>
<tr>
<th>Siphon</th>
<th>no. of pipes</th>
<th>total area</th>
<th>discharge coeff. m</th>
</tr>
</thead>
<tbody>
<tr>
<td>siphon1</td>
<td>2</td>
<td>8</td>
<td>0.32</td>
</tr>
<tr>
<td>siphon2</td>
<td>1</td>
<td>4</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Figure 5 The measured discharge coefficients for the siphons

Figure 5 shows a deviation between the measurements and the fits. For siphon 2 this may be explained from the unknown level of the Sasik channel at the time of the measurements. For siphon 1 the deviation may be caused by the fact that the levels at both sides of the siphon are approximately equal, varying from 1 to 4 cm. The accuracy of the level measurements is 1 cm at best so the measured head Δh has a large relative uncertainty. Also, for such a small value, the resistance of the pipe may well depend on discharge, so that m is no longer constant.

Van der Vat (1996) suggested, from visual inspection, that there may be leakage from siphon 1 into the Sasik Channel. Such leakage was not found in these measurements.

3.2 Water levels in the Plavny

The water levels in the Plavny were measured daily at 8 different locations during the survey of 1997. These locations are for the Stentsovsko Plavny: Tupikovy lock at both sides of the weir and a gauge meter near the Hunter economy. For the Zebrijanske Plavny: Lock 4 and 5 at both sides of the weirs and a gauge meter near the Fisher economy.

The levels at the gauge meters were transformed to absolute levels in the Baltic system (the average level of the Black Sea is approximately at -0.1 m in the Baltic system). Near each gauge meter is a benchmark of the Baltic system. There is a benchmark in the church of Primorske, which was used to level the gauge meters around lock 4 and 5. A benchmark within hundred meter of siphon 2 was used to determine the level of the gauge meters at siphon 1, siphon 2, the Fisher economy and the hunter economy. The level of the gauge meters at the Tupikovy lock was determined from a benchmark near the Mezcolhozny lock.
Water level at the locks

The water levels near the locks are shown in Figure 5 below. The Tupikovy lock damps the fluctuations in the Mezcolhozny channel and locks 4 and 5 can keep the levels in the Zebrijanske Plavny above the level of the Black Sea. When the locks were opened in September 1997, the level in the Plavny quickly decreased to the level Black Sea (or rather Zebrijanske Bay).

Figure 5 The water levels at the locks
Figure 5 also shows that the level in the Stentsovsko Plavny and the Zebrijanske Plavny is not the same. In the summer time, the level at the Tupikovy lock was +0.5 m while it was +0.3 m at locks 4 and 5. There is a gradient in the level, caused by the flow through the Plavny which is directed to the Black Sea. In September 1997 the level in the Zebrijanske Plavny quickly decreases from +0.3 m to almost 0 m. There is no such decrease in the Stentsovsko Plavny. This shows that the flow from the Stentsovsko Plavny to the Zebrijanske Plavny through siphon 1 is relatively small, or at least it is not large enough to constitute similar levels in the Plavny.

Figure 6 compares the water levels as measured at different locations in the Plavny. The levels in the Stentsovsko Plavny are much closer to each other than the water levels in the Zebrijanske Plavny. Indeed, the level at the Fisher Economy in Zebrijanske is closer to the Hunter Economy in Stentsovsko than to the level at lock 5. There seems to be a large gradient in the water level in the Zebrijanske Plavny. It is the question whether this gradient is caused by a measurement error or whether this is an actual phenomenon.

![Water levels in the Plavny](image)

**A possible error in the water levels**

A gradient of the water level causes a water flow. So if the measurements are correct, there is a constant water flow in the Zebrijanske Plavny from the Fisher Economy to Locks 4 and 5. This flow may be caused by the pumping station at the Fisher Economy, although this station has a relatively small discharge and it does not operate all the time. There is also another explanation and that is an error of measurement at Locks 4 and 5.

The gauges at locks 4 and 5 were levelled from the benchmark in the Primorsko church which is located within 1 km, using a standard surveyor’s levelling pole. The standard error for these type of measurements in mm is \(3\sqrt{L}\) for \(L\) in km, which is equal to 3 mm in this case.
Therefore, if there is a systematic error of 0.2 m, it would have to be in the reading of the benchmark. The level of the benchmark has last been recorded by the Ukrainian Land Survey in 1977. An error in the reading of the benchmark is unlikely, but now and then such errors occur. As an error in benchmark is not very likely and as a similar gradient of the water levels is shown on the State Map of the Plavny, it is assumed that the water level data at locks 4 and 5 is correct. To rule out a possible error it is advisory to repeat the levelling of the gauge meters by measuring in between two benchmarks.

**A cross section of the water level**

The occasional measurements during the field trips give a good impression of the water level across the Plavny, which is shown in Figure 7. There is no constant gradient in the Stentsovsko Plavny, sometimes the level is higher at the siphon and sometimes it is higher at the Tupikovy lock. The differences are probably caused by wind and by fluctuations of the Mezcolhozny channel. There may also be a minor error in the water levels of a few cm, because the average level at the siphon is somewhat higher than the level at the lock. In the Zebrijanske Plavny there is a constant gradient directed to the Black Sea. This confirms the level difference between the Fisher Economy and Lock 4.

![Figure 7: The water levels measured during the field trips](image)

The distance from the Tupikovy lock to Siphon 1 is approximately 8 km and the distance from Siphon 1 to Lock 4 is approximately 3.5 km

### 3.3 Water levels in the Danube and the Sasik channel

Both the Mezcolhozny channel and the Sasik channel are connected to the Danube through mechanically operated locks, which are of a much larger size than the locks in the Plavny. The Sasik lock keeps the level in the Sasik channel at approximately +0.2 m. The level variations are only minor. The level in the Mezcolhozny channel shows much more variation. During the survey of 1997, the Mezcolhozny lock was open and the level in the Mezcolhozny channel and the Danube were approximately the same.
The Mezcolhozny lock only closes if the water level in the Danube is too high, somewhere in between +1–+1.5 m. The operator decides when the lock has to be closed.

The water level in the Danube is a boundary condition in the water balance model. The level at the Mezcolhozny lock is not available in long time series. The nearest station with long time series is in Kilya. The water level in Kilya is compared to the water level near the Mezcolhozny lock in Figure 8.

![Danube water levels](image)

Figure 8 The water level in the Danube at Kilya and the Mezcolhozny channel during the survey period

The water levels at Kilya and Mezcolhozny can be correlated by linear regression. By least squares this gives that $h_{\text{mezcolhozny}} = 0.87h_{\text{kilya}} - 0.28$, which converts the Kilya time series to a Mezcolhozny time series.
4 Water balance of 1997

This chapter contains the water balance prepared by the IBSS. First the necessary data is reviewed.

4.1 Bathymetry of the Plavny

The dense reed beds in the Plavny obstruct an easy measurement of the bathymetry. Various methods have been proposed, like measurements over ice, measurements from a helicopter and measurements of a few cross sections. So far such a campaign has not been carried out. The IBSS has prepared an adhoc bathymetry of the Plavny, as shown in Figure 9.

![Diagram showing bathymetry](image)

Figure 9 The bathymetry of the Plavny determined by IBSS from the State Map

The relation between volume and depth is almost linear, which means that the volume is equal to (total area) × (level-bottom level). IBSS also prepared an estimate on the area percentage of open water and reed bed for the Plavny. These values are shown in Table 3.

Table 3 The bathymetry of the Plavny

<table>
<thead>
<tr>
<th>Bathymetry</th>
<th>Stentsovsko</th>
<th>Zebrijanskij</th>
</tr>
</thead>
<tbody>
<tr>
<td>total area</td>
<td>50 km²</td>
<td>37 km²</td>
</tr>
<tr>
<td>bottom level</td>
<td>-0.49 m</td>
<td>-0.78 m</td>
</tr>
<tr>
<td>percentage open water</td>
<td>50%</td>
<td>30%</td>
</tr>
</tbody>
</table>

4.2 Meteorology

The precipitation in the Plavny is measured at the Hunter economy. The measured precipitation has been compared to the precipitation measured at the meteorological station at Vilkovo, which is a few kilometres from the Plavny. No significant differences were found. The rainfall at Vilkovo has been used for the water balance model.
The evapotranspiration is computed from Dalton’s law as adapted for local circumstances by the Ukrainian Hydrometeorological Institute:

\[ E = 0.2(1 + 0.56u)(E_w - E_a) \]  

(2)

- **E** = evaporation rate [mm/day]
- **u** = wind velocity at 2 m [m/s]
- **E_w** = saturated vapour pressure at actual water temperature [mbar]
- **E_a** = actual vapour pressure [mbar]

The vapour pressures are calculated from the measured dry and wet bulb temperature and the water temperature according to the psychometric tables of the World Meteorological Organisation. The equation (2) has been calibrated only for open water evaporation, but it is also used for the evapotranspiration in the wetland, because it is undetermined if this is higher or lower than the open water evaporation (Mitsch and Gosselink, 1986).

### 4.3 Pumping stations

There are 6 pumping stations north-west of the Stentsovsko Plavny. There is only one pumping station in the Zebrijanske Plavny, which is located at the Fisher economy (fish ponds). Each of the 6 stations in the Stentsovsko Plavny has a restricted maximal volume, which has been assigned to protect the Plavny. The sum of the maximal volume of all the 6 pumping stations is 40 million m³ per year. This is almost equal to the average wet volume of the Plavny. In reality, this maximal volume has not been reached over the last ten years. The drainage volume for the Stentsovsko Plavny was 15.7 million m³ in 1997. The drainage volume from the Fisher economy in the Zebrijanske Plavny was 2.7 million m³ in 1997.

### 4.4 Filtration through the dams and upwelling

There is filtration through the dams surrounding the Plavny. The precise quantity of the filtration has never been determined and can only be estimated using theoretical considerations. The dams surrounding the Plavny are the dykes on both sides of the Sasik channel and the dam between the Zebrijanske Plavny and Zebrijanske Bay. The filtration is only minor compared to the other volumes in the water balance.

As mentioned in (Van der Vat 1997) there may be upwelling of Danube water in the Zebrijanske Plavny, which has been witnessed in relative cold water masses in field surveys of the IBSS. Again, this quantity can only be determined form theoretical considerations and can only be minor.
4.5 Water balance over 1997

Based on the data as described above, IBSS has prepared a water balance for the period April to November 1997. The volumes in the water balance have been determined as follows:

The balance term (= storage) has been computed from the measured water level combined with the relation between volume and level as exhibited in section 4.1. The water level for the Stentsovsko Plavny has been taken from the Tupikovy lock. The water level for the Zebrianske Plavny has been taken from lock 4. The precipitation has been taken from the meteorological station in Vilkovo. The evapotranspiration has been computed by Dalton’s Law from the dry and wet bulb temperature. The pumping volumes have been obtained from the irrigation authorities. The exchange volumes through the locks have been computed from the discharge formula through a weir with the measured discharge coefficients, the observed shutter heights and the daily observed water levels. The exchange volume through the siphon has been computed from the measured discharge coefficients and the monthly observed water levels, interpolating levels in between the measurements (this probably contributes largely to the error in the balance). The error term closes the water balance.

The IBSS water balance is given in Figure 10 and 11 and Table 4 and 5.

Figure 10 The water balance for the Stentsovsko Plavny per month
Figure 11: The water balance for the Zebrijanske Plavny

Table 4

<table>
<thead>
<tr>
<th>Water balance for Stentsovsky plavni (1.04 - 30.11.97)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1E8m³</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>IN Balance Typlový drainage precipitatio SUM</td>
</tr>
<tr>
<td>OUT evaporation siphon 1 filtration siphon 2 SUM Error</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>april 1.69 4.08 0.99 3.17 8.25 -3.34 -2.49 -0.0020 -0.63 -8.48 -3.44</td>
</tr>
<tr>
<td>may -4.42 8.83 2.74 2.93 14.50 -4.60 -3.03 -0.0020 -0.73 -8.36 -1.71</td>
</tr>
<tr>
<td>june 4.97 1.84 2.09 4.09 7.82 -5.84 -2.48 -0.0010 -0.58 -8.90 -3.90</td>
</tr>
<tr>
<td>july -2.76 -0.47 3.60 5.22 8.35 -8.93 -2.46 -0.0010 -0.58 -11.95 6.35</td>
</tr>
<tr>
<td>august -3.88 2.18 2.85 9.37 14.39 -6.17 -4.56 -0.0020 -0.80 -11.54 1.02</td>
</tr>
<tr>
<td>september 9.81 -4.64 0.26 0.14 -4.25 -3.95 -2.92 -0.0020 -0.62 -7.49 1.93</td>
</tr>
<tr>
<td>october -1.64 -0.96 0.94 1.38 1.35 -3.73 -2.91 -0.0010 -0.48 -7.13 7.42</td>
</tr>
<tr>
<td>november 5.49 -0.49 1.02 1.65 2.18 -2.63 -2.16 -0.0010 -0.41 -5.10 -2.55</td>
</tr>
</tbody>
</table>

Table 5

<table>
<thead>
<tr>
<th>Water balance for Zebrijanskie plavny</th>
</tr>
</thead>
<tbody>
<tr>
<td>1E8m³</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>IN Balance siphon 1 drainage precipitatio SUM</td>
</tr>
<tr>
<td>OUT evaporation/filtration lock 4 lock 5 SUM Error</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>april -0.84 2.49 0.48 1.64 4.61 -1.63 -0.02 -2.6790 -1.32 -5.65 1.88</td>
</tr>
<tr>
<td>may -0.52 3.03 0.06 1.96 5.05 -2.34 -0.02 -1.9580 -0.41 -4.79 0.26</td>
</tr>
<tr>
<td>june -0.84 2.48 0.18 2.16 4.82 -2.97 -0.01 -1.9980 -0.42 -5.40 1.42</td>
</tr>
<tr>
<td>july 0.64 2.46 0.06 1.91 4.43 -4.54 -0.01 -1.8750 -0.40 -8.93 1.56</td>
</tr>
<tr>
<td>august -0.52 4.58 0.06 4.62 9.24 -3.13 -0.02 -3.2330 -2.25 -8.84 0.08</td>
</tr>
<tr>
<td>september 7.31 2.92 0.14 0.07 3.13 -2.00 -0.02 -3.5810 -2.93 -8.51 -1.93</td>
</tr>
<tr>
<td>october 1.12 2.91 0.55 0.71 4.17 -1.92 -0.01 -3.3600 -2.12 -7.41 2.12</td>
</tr>
<tr>
<td>november -0.59 2.16 0.21 0.90 3.26 -1.30 -0.01 -0.8550 -0.71 -2.47 0.17</td>
</tr>
</tbody>
</table>
The error in the water balance is relatively smaller for the Zebrijanske Plavny. The error is caused by the interpolation of the water levels for the siphons, errors in the computation of the evapotranspiration, local variations of the precipitation and tampering with the shutter heights by unauthorised personnel. This error term is more or less complementary for the Stentsovsko and the Zebrijanske Plavny for the months April, June and September. This indicates that the estimated flow through the siphon (interpolated levels) contributes largely to the error.

According to the water balance there is a more or less constant flow through the siphon from the Stentsovsko into the Zebrijanske Plavny. There is also a more or less constant outflow through lock 4 and 5. The flow through the Tupikovy lock is much more irregular, sometimes flowing into the Plavny, sometimes flowing out to the Mezcolhony channel. Drainage is an important part of the water balance for the Stentsovsko Plavny.

The evapotranspiration is the largest volume, which is more or less constant throughout the year. Nevertheless, the balance indicates that the hydrological conditions in the Plavny depend largely on the management of the locks, for which the volumes are of comparable magnitude. A different management may give different hydrological conditions.
5 The water balance model SZP HYDRO

SZP HYDRO is a water balance model of the Stentsovsko-Zebrijanske Plavny. This chapter contains a description of the set up of the model and the method of calibration. The Stentsovsko-Zebrijanske Plavny is a mosaic wetland of open water and reed beds. It is not possible to capture such a heterogeneous landscape in the balance model. SZP HYDRO has been developed to support the plan forming of specialists.

5.1 The layout of the model

The water balance model divides the Plavny into compartments as shown in Figure 12a.

![Diagram of water balance model](image)

Figure 12a The compartments and the flow in the water balance model

The model has five compartments. Both the Stentsovsko and the Zebrijanske Plavny are divided into a compartment for open water and a compartment for reed. This division is made because the increase of the reed beds and the decrease of the open water is a main concern for the Plavny. Therefore it is important to model the balance of these areas separately for future water quality modelling.

The hydraulic boundary conditions of the model are:

- The water level in the Danube at the Mezcolhozny lock
- The water level of the Zebrijanske Bay at Lock 4 and 5
- The water level of the Sasik channel (in the model this is assumed constant).
The hydrological boundary conditions are:

- precipitation
- evapotranspiration
- drainage.

This is sketched in Figure 12b.

Figure 12b The structures and the boundary conditions in the water balance model

The arrows in Figure 12a represent all the flows in the water balance model. There are two types of flows: flows determined by water management and flows determined by nature. The flows through the locks and the siphons are determined by the water management in the Plavny. These flows are represented by bold arrows as they are of main concern in the present study. The other flows are represented by thin arrows. The volumes of the pumping station at the end of the Mezcolhonzny are not yet included in the model, as these volumes were not available in time.

SZP HYDRO is programmed in EXCEL® version 6.0 and it can be handled by simple click and go commands. The user may change the management and the size of each lock, the empirical coefficients for evapotranspiration (both over water and reed), the coefficients for the exchange volumes between open water and reed land, and the coefficients for filtration. The model also computes the salt balance, but this balance has not been calibrated in this study. Technical information on the model is contained in appendix A.

5.2 The flows in the model

The model computes the daily volumes which are associated to the flows. For every compartment, the incoming and the outgoing flows are computed and this gives the actual volume of water in the compartment. The water level in the compartment is computed from the bathymetry as described in Chapter 3.8.
The flows in the model are computed as follows:

- The discharge through the locks and the siphon is computed from equation (1) where the water levels at both sides of the structure are taken equal to the computed water level in the compartment.
- The precipitation is computed from the measured rainfall in mm/day multiplied by the area of the compartment.
- The evapotranspiration is computed from Dalton's law (2) with the empirical coefficients as derived by the Ukrainian Hydrometeorological Institute.
- The drainage volumes are taken from the Irrigation Authorities as monthly values, divided evenly over the days of the month.
- The upwelling and the filtration are computed from standard formulas for groundwater flow.

The only flow which needs further discussion is the exchange between open water and reed land. In a hydrodynamical model of a lagoon in a mangrove forest, Taal modelled the mangrove forest and the open water using Darcy's law for the flow in the mangrove forest (Taal, 1994). A reed land is very much like a mangrove forest and it is reasonable to use Darcy's law in our water balance model as well. In particular, the exchange between the open water and the reed land reads:

$$Q = kA\Delta h / L$$  \hspace{1cm} (3)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q$</td>
<td>exchange volume</td>
<td>$[m^3/\text{day}]$</td>
</tr>
<tr>
<td>$k$</td>
<td>friction coefficient</td>
<td>$[\text{m/day}]$</td>
</tr>
<tr>
<td>$A$</td>
<td>exchange area between the compartment</td>
<td>$[m^2]$</td>
</tr>
<tr>
<td>$\Delta h$</td>
<td>difference between the water levels of the compartments</td>
<td>$[m]$</td>
</tr>
<tr>
<td>$L$</td>
<td>average distance between the two compartments</td>
<td>$[m]$</td>
</tr>
</tbody>
</table>

It should be noted that the one compartment for reed land in the model in reality comprises of a mosaic landscape of reed beds in between open water. The exchange area $A$ and the average distance $L$ can only be estimated very roughly and can be tuned only by a proper calibration of the salt balance.

The model calibration is carried out for two different boundary conditions. In the first calibration the Black Sea boundary condition is taken equal to the measured levels at Locks 4 and 5. In the second calibration the boundary condition is taken equal to the measured levels plus 0.2 m, for the reasons discussed in Chapter 3.

5.3 The calibration of the model

The model is calibrated on the collected data which has been discussed in Chapter 3. As in any calibration, the first question is which parameters should be varied. The main quantities in the water balance are the precipitation, the evapotranspiration and the discharges through the locks. Of these quantities, the discharges through the locks are relatively uncertain and they show the largest variation. Therefore the varied parameters in the calibration are the discharge coefficients of the locks.
The model is calibrated on the measured water levels. The water levels have been measured at several locations in the Plavny. The level at the Tupikovy lock is most representative for the open water level in the Stentsovsko Plavny. The water level at Lock 4 and 5 is most representative for the open water level in the Zebrjanske Plavny (Egorashenko, 1998). It would be useful to install divers at siphon 1, so the water levels can registered at the two ends of the Plavnys.

The model is not calibrated on the exchange between open water and reed bed, since there is no method to obtain the exchange volume from the present data. A proper calibration of the exchange is possible if the model is calibrated on the salt balance, since salinity is a good tracer to measure exchange volumes. As for now, the exchange area has been estimated from the State Map and the Darcy coefficient has been taken equal to a value used by Taal to model the mangrove forest.

The model calibration is carried out for two different boundary conditions, since there may be an error in the measurements at Locks 4 and 5.

**Calibration for the measured water levels at Lock 4 and 5**

The simulation is carried out for the entire year 1997 and not only for the survey period of April-November. The first three months are used to adapt to the initial conditions. This is possible because the meteorological conditions and the Danube levels are known for these months. The level of the Black Sea is kept constant in the initial three months. The position of the shutters is taken equal to the position in April.

The discharge coefficients which were obtained in the calibration are shown in Table 6.

Table 6 The calibrated values of the discharge coefficients

<table>
<thead>
<tr>
<th>Discharge coefficient</th>
<th>tupikovy lock</th>
<th>siphon 1</th>
<th>siphon 2</th>
<th>lock 4</th>
<th>lock 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>SZA HYDRO</td>
<td>0.60</td>
<td>0.07</td>
<td>0.02</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>measured</td>
<td>0.60</td>
<td>0.03</td>
<td>0.03</td>
<td>0.55</td>
<td>0.52</td>
</tr>
</tbody>
</table>

For siphon 1 the calibrated value is much lower than the measured value. The reason is that the model uses the *average* level over an entire compartment to compute the discharge through the structure. The measurements use the *local* levels at a structure to determine the discharge. As was shown in Chapter 3, there is a gradient in the water level so the local levels and the average levels are different, for the Zebrjanskij Plavny in particular. That is why there is a difference between the measured and the calibrated discharge coefficients.

The resulting water levels in the Plavny are shown in Figure 13 below. The simulated level in the Stentsovsko Plavny agrees with the measurements. For the Zebrjanske Plavny there is a larger difference. The simulated level is higher than the level at Lock 4, which is representative for the level of the open water. The initial condition in the model is higher than the measured level, which is caused by the fact that the model also simulates the first three months of the year, for which there is no data on the lock management.
In the Zebrijanske Plavny, the measured water level drops quickly in the month September while it drops more slowly in the model simulations. This may be due to an error in the measured boundary condition (= level of Zebrijanske Bay). The Hydrometerological Institute has data on the water level in the Bay which is much lower than the level measured by the IBSS in September (see Chapter 6, figure 18).

Figure 13 The computed water levels compared to the measured water levels

Observe that the simulated level in September-November descends too quickly in the Stentsovsko Plavny, compared to the measurements. In the Zebrijanske Plavny, the simulated water level descends too slowly. A possible explanation is that the water level in the Zebrijanske Plavny as measured at lock 4 responds more quickly than the average water level to the opening of the locks 4 and 5 in September. In the same vein, the level at the Tupikovy lock responds more slowly than the average level in the Stentsovsko Plavny, because the Tupikovy lock is most remote to locks 4 and 5.

**Calibration for the water levels at Locks 4 and 5 +0.2 m**

There may be an error in the measured water levels at Lock 4 and 5 of approximately 0.2 m, as discussed in Chapter 3. That is why the model is also calibrated for a boundary condition of measured water levels +0.2 m. The discharge coefficients for this calibration are shown in Table 7.
Table 7 The calibrated values of the discharge coefficients for the Black Sea water level +0.2 m.

<table>
<thead>
<tr>
<th>Discharge coefficient</th>
<th>tupikovy lock</th>
<th>siphon 1</th>
<th>siphon 2</th>
<th>lock 4</th>
<th>lock 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>SZP HYDRO</td>
<td>0.60</td>
<td>0.15</td>
<td>0.02</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>measured</td>
<td>0.60</td>
<td>0.32</td>
<td>0.03</td>
<td>0.55</td>
<td>0.52</td>
</tr>
</tbody>
</table>

In this new calibration, it turns out that only the discharge coefficient of siphon 1 needs to be adapted. In the model, the new boundary condition causes higher water levels in the Zebrianske Plavny. Hence, in the model the level difference $\Delta h$ between the Stentsovsko Plavny and Zebrianske Plavny decreases. This is compensated by an increase of the discharge coefficient.

The simulated water levels are shown in Figure 14. For the Stentsovsko Plavny, the results are comparable to the calibration in section 3.2. For the Zebrianske Plavny there is a difference. The measured water level at Lock 4 has been increased by 0.2 m. The simulated water level during April-August agrees better with the increased level. For the period September-November the results are similar to the calibration in section 3.2.

![Water level in Stentsovsko Plavny](image)

Figure 14 The water levels for the calibration +0.2 m
Conclusions from the calibration

The calibration shows that the discharge coefficient of siphon 1 in the model is half or less the measured coefficient. This difference can only be explained from local variations of the water level. In this respect, the model confirms the gradient of the water level measured in the Zebrijanske Plavny. If the gradient is removed, the siphon will carry double or more of its present discharge.

At the Zebrijanske side of the siphon, there is a small stream which leads the water to the Dzebrjanovski Lake north-east of the siphon. There is also a large channel going south, but this channel has a dead end not far from the Fisher economy. From visual inspection, the small stream behind the siphon is approximately 2 m wide and 1 m deep. The discharge through the siphon is approximately 1 m³/s. For an average Chézy value of 40 m·s⁻¹ this gives a gradient of 0.0004. The length of the stream is approximately 1 km, which would mean that the level difference between Dzebrjanovsky Lake and the siphon is 4 dm. So it is possible that there is a large gradient across the Zebrijanske Plavny.

It is likely that the stream does not carry the entire discharge of the siphon, giving a smaller gradient, but it appears that the gradient is caused by a flow from the from the siphon through the Dzebrjanovsky Lake to the Black Sea through Locks 4 and 5. If the stream is enlarged the gradient will be removed, which will increase the flow. An additional possibility is to reconnect the siphon to the old rivers through the Plavny, which will also increase the flow. This will restore the flow through the Zebrijanske Plavny to the situation of before 1980, when the Sasik channel was built.

5.4 The computed water balance

The computed water balance by the model is shown in Table 8 and 9. The volumes in the balance are approximately equal for both versions of the calibration. The water balance is computed for the entire year 1997.

The water balance can be compared to the water balance prepared by the IBSS as exhibited in the previous chapter. The main difference between the computed balance and the SZP HYDRO balance is the discharge through Lock Tupikovy. In the simulations the lock has been closed in the beginning of August and July because otherwise the water level in the Stensovsko Plavny would decrease very rapidly. The motivation is the locks were probably closed by unauthorised personnel (fishermen prefer the locks to be closed).
Table 8 Water balance Stentsovsko

Water Balance

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Water balance for Stentsovsko plavni</th>
<th>Mean volume</th>
<th>Teplicky drainage</th>
<th>evaporation</th>
<th>sinkholes 1</th>
<th>sinkholes 2</th>
<th>SUM</th>
<th>SUM</th>
<th>SUM</th>
<th>SUM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m</td>
<td>min. m3</td>
<td>min. m3</td>
<td>m m3</td>
<td>min. m3</td>
<td>m3</td>
<td>m3</td>
<td>m3</td>
<td>m3</td>
<td>m3</td>
</tr>
<tr>
<td>January</td>
<td>0.30</td>
<td>0.64</td>
<td>23</td>
<td>98.27</td>
<td>-0.029</td>
<td>0.670</td>
<td>1.287</td>
<td>-1.667</td>
<td>-7.321</td>
<td>-0.678</td>
</tr>
<tr>
<td>February</td>
<td>0.84</td>
<td>0.56</td>
<td>11</td>
<td>83.09</td>
<td>-0.303</td>
<td>0.605</td>
<td>0.811</td>
<td>-2.469</td>
<td>-2.472</td>
<td>-0.039</td>
</tr>
<tr>
<td>March</td>
<td>0.56</td>
<td>0.51</td>
<td>37</td>
<td>59.00</td>
<td>-0.033</td>
<td>0.725</td>
<td>2.055</td>
<td>-3.425</td>
<td>-1.034</td>
<td>-0.054</td>
</tr>
<tr>
<td>April</td>
<td>0.51</td>
<td>0.55</td>
<td>66</td>
<td>50.80</td>
<td>4.377</td>
<td>1.156</td>
<td>0.580</td>
<td>-3.965</td>
<td>-2.948</td>
<td>-0.314</td>
</tr>
<tr>
<td>May</td>
<td>0.35</td>
<td>0.64</td>
<td>87</td>
<td>82.12</td>
<td>6.406</td>
<td>2.723</td>
<td>2.756</td>
<td>-6.625</td>
<td>-3.626</td>
<td>-0.093</td>
</tr>
<tr>
<td>June</td>
<td>0.64</td>
<td>0.46</td>
<td>80</td>
<td>57.16</td>
<td>8.075</td>
<td>2.219</td>
<td>4.369</td>
<td>-9.088</td>
<td>-0.064</td>
<td>-0.038</td>
</tr>
<tr>
<td>July</td>
<td>0.45</td>
<td>0.47</td>
<td>63</td>
<td>32.54</td>
<td>5.890</td>
<td>3.570</td>
<td>0.449</td>
<td>-8.004</td>
<td>-1.571</td>
<td>-0.443</td>
</tr>
<tr>
<td>August</td>
<td>0.47</td>
<td>0.50</td>
<td>183</td>
<td>57.91</td>
<td>3.790</td>
<td>2.656</td>
<td>6.954</td>
<td>-5.988</td>
<td>-1.520</td>
<td>-0.582</td>
</tr>
<tr>
<td>September</td>
<td>0.55</td>
<td>0.59</td>
<td>92</td>
<td>52.80</td>
<td>-0.074</td>
<td>0.027</td>
<td>0.485</td>
<td>-3.981</td>
<td>-4.381</td>
<td>-0.471</td>
</tr>
<tr>
<td>October</td>
<td>0.39</td>
<td>0.27</td>
<td>27</td>
<td>45.54</td>
<td>-0.054</td>
<td>0.064</td>
<td>1.480</td>
<td>-3.630</td>
<td>-0.146</td>
<td>-0.342</td>
</tr>
<tr>
<td>November</td>
<td>0.27</td>
<td>0.24</td>
<td>38</td>
<td>41.81</td>
<td>-0.030</td>
<td>0.866</td>
<td>1.991</td>
<td>-2.493</td>
<td>-1.608</td>
<td>-0.197</td>
</tr>
<tr>
<td>December</td>
<td>0.24</td>
<td>0.26</td>
<td>44</td>
<td>42.45</td>
<td>0.018</td>
<td>0.583</td>
<td>2.355</td>
<td>-1.009</td>
<td>0.014</td>
<td>-0.244</td>
</tr>
</tbody>
</table>

Year: 0.30 0.28 0.65 53.82 9.482 17.076 34.925 47.106 -34.451 -5.874 -2.0044 -25.772

Water balance computed by SZP HYDRO

<table>
<thead>
<tr>
<th>IN</th>
<th>OUT</th>
<th>SUM</th>
<th>SUM</th>
<th>SUM</th>
<th>SUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balance</td>
<td>Teplicky drainage</td>
<td>precipitation</td>
<td>SUM</td>
<td>evaporation</td>
<td>sinkholes</td>
</tr>
<tr>
<td>april</td>
<td>1.66</td>
<td>4.08</td>
<td>0.99</td>
<td>3.17</td>
<td>8.25</td>
</tr>
<tr>
<td>may</td>
<td>-4.42</td>
<td>8.83</td>
<td>2.74</td>
<td>2.93</td>
<td>14.50</td>
</tr>
<tr>
<td>June</td>
<td>4.97</td>
<td>1.64</td>
<td>2.09</td>
<td>4.09</td>
<td>7.82</td>
</tr>
<tr>
<td>July</td>
<td>-2.76</td>
<td>-0.47</td>
<td>3.60</td>
<td>5.22</td>
<td>8.35</td>
</tr>
<tr>
<td>August</td>
<td>-3.88</td>
<td>2.18</td>
<td>2.85</td>
<td>9.37</td>
<td>14.39</td>
</tr>
<tr>
<td>september</td>
<td>9.81</td>
<td>-6.44</td>
<td>0.26</td>
<td>0.14</td>
<td>-4.25</td>
</tr>
<tr>
<td>October</td>
<td>-1.64</td>
<td>-0.98</td>
<td>0.94</td>
<td>1.38</td>
<td>1.35</td>
</tr>
<tr>
<td>November</td>
<td>0.46</td>
<td>-0.49</td>
<td>1.02</td>
<td>1.65</td>
<td>2.18</td>
</tr>
</tbody>
</table>

Monthly Water Balance Stentsovsko Plavni

<table>
<thead>
<tr>
<th>10^6 m3</th>
<th>TOTAL BALANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balance</td>
<td>-6.93</td>
</tr>
<tr>
<td>diffuse</td>
<td>-6.62</td>
</tr>
<tr>
<td>sinkhole1</td>
<td>-7.49</td>
</tr>
<tr>
<td>sinkhole2</td>
<td>-7.13</td>
</tr>
<tr>
<td>evaporation</td>
<td>-7.32</td>
</tr>
<tr>
<td>sinkholes 1</td>
<td>-11.38</td>
</tr>
<tr>
<td>sinkholes 2</td>
<td>-11.95</td>
</tr>
</tbody>
</table>

The water balance of SZP HYDRO as a bar chart
### Table 9 Water balance Zebrijanske

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Ctrl</th>
<th>Hřbitov</th>
<th>Mean</th>
<th>Volume</th>
<th>precip</th>
<th>fishpond</th>
<th>evapor lock 4</th>
<th>lock 5</th>
<th>upwelling</th>
<th>Sasik c</th>
<th>Black c</th>
<th>T-F-O</th>
<th>day/mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>0.65</td>
<td>0.55</td>
<td>29.09</td>
<td>7.321</td>
<td>0.635</td>
<td>0.368</td>
<td>0.644</td>
<td>0.093</td>
<td>0.070</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>7.491</td>
</tr>
<tr>
<td>February</td>
<td>0.56</td>
<td>0.64</td>
<td>29.01</td>
<td>2.727</td>
<td>0.311</td>
<td>0.240</td>
<td>0.022</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>1.792</td>
</tr>
<tr>
<td>March</td>
<td>0.54</td>
<td>0.47</td>
<td>28.91</td>
<td>1.044</td>
<td>0.090</td>
<td>0.020</td>
<td>-1.744</td>
<td>-0.337</td>
<td>-0.283</td>
<td>0.072</td>
<td>0.000</td>
<td>0.005</td>
<td>0.073</td>
</tr>
<tr>
<td>April</td>
<td>0.47</td>
<td>0.50</td>
<td>29.74</td>
<td>2.358</td>
<td>0.568</td>
<td>0.250</td>
<td>-1.713</td>
<td>-0.234</td>
<td>-1.062</td>
<td>0.067</td>
<td>0.000</td>
<td>0.020</td>
<td>0.320</td>
</tr>
<tr>
<td>May</td>
<td>0.50</td>
<td>0.59</td>
<td>29.97</td>
<td>3.628</td>
<td>2.432</td>
<td>0.062</td>
<td>-0.355</td>
<td>-0.565</td>
<td>-0.466</td>
<td>0.070</td>
<td>0.000</td>
<td>1.768</td>
<td>0.311</td>
</tr>
<tr>
<td>June</td>
<td>0.59</td>
<td>0.45</td>
<td>31.06</td>
<td>0.964</td>
<td>2.234</td>
<td>0.169</td>
<td>-0.002</td>
<td>1.593</td>
<td>0.451</td>
<td>0.067</td>
<td>0.000</td>
<td>1.665</td>
<td>0.36</td>
</tr>
<tr>
<td>July</td>
<td>0.46</td>
<td>0.40</td>
<td>28.13</td>
<td>1.571</td>
<td>1.756</td>
<td>0.054</td>
<td>-4.426</td>
<td>-1.253</td>
<td>-0.374</td>
<td>0.070</td>
<td>0.000</td>
<td>2.003</td>
<td>0.311</td>
</tr>
<tr>
<td>August</td>
<td>0.40</td>
<td>0.44</td>
<td>28.75</td>
<td>4.520</td>
<td>4.566</td>
<td>0.061</td>
<td>-3.048</td>
<td>-2.817</td>
<td>-1.840</td>
<td>0.070</td>
<td>0.000</td>
<td>1.704</td>
<td>0.311</td>
</tr>
<tr>
<td>September</td>
<td>0.44</td>
<td>0.29</td>
<td>27.48</td>
<td>4.351</td>
<td>0.252</td>
<td>0.171</td>
<td>-1.935</td>
<td>-2.758</td>
<td>-3.023</td>
<td>0.067</td>
<td>0.000</td>
<td>2.875</td>
<td>0.26</td>
</tr>
<tr>
<td>October</td>
<td>0.29</td>
<td>0.20</td>
<td>25.10</td>
<td>4.140</td>
<td>0.763</td>
<td>0.520</td>
<td>-1.849</td>
<td>-3.308</td>
<td>-2.441</td>
<td>0.070</td>
<td>0.000</td>
<td>2.107</td>
<td>0.311</td>
</tr>
<tr>
<td>November</td>
<td>0.20</td>
<td>0.24</td>
<td>23.80</td>
<td>1.609</td>
<td>1.014</td>
<td>0.214</td>
<td>-1.296</td>
<td>-0.706</td>
<td>-0.912</td>
<td>0.067</td>
<td>0.000</td>
<td>0.017</td>
<td>0.311</td>
</tr>
<tr>
<td>December</td>
<td>0.24</td>
<td>0.28</td>
<td>25.73</td>
<td>0.914</td>
<td>1.221</td>
<td>0.227</td>
<td>-0.554</td>
<td>-0.203</td>
<td>-0.418</td>
<td>0.067</td>
<td>0.000</td>
<td>0.824</td>
<td>0.311</td>
</tr>
</tbody>
</table>

The water balance computed by SZP HYDRO (fish ponds = the drainage from the 1 pumping station in ZP)

### Table 10 The water balance prepared by the IBSS

<table>
<thead>
<tr>
<th>Conditions</th>
<th>IN</th>
<th>drainage</th>
<th>precip</th>
<th>SUM</th>
<th>OUT</th>
<th>evaporation</th>
<th>filtration</th>
<th>lock 4</th>
<th>lock 5</th>
<th>SUM</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>april</td>
<td>-0.84</td>
<td>2.48</td>
<td>0.48</td>
<td>1.64</td>
<td>4.61</td>
<td>-1.63</td>
<td>-0.02</td>
<td>2.6790</td>
<td>-1.32</td>
<td>-5.65</td>
<td>1.88</td>
</tr>
<tr>
<td>may</td>
<td>-0.52</td>
<td>3.03</td>
<td>0.06</td>
<td>1.95</td>
<td>5.05</td>
<td>-2.34</td>
<td>-0.02</td>
<td>-1.9580</td>
<td>-0.41</td>
<td>4.79</td>
<td>0.26</td>
</tr>
<tr>
<td>june</td>
<td>-0.84</td>
<td>2.48</td>
<td>0.18</td>
<td>2.16</td>
<td>4.82</td>
<td>-2.97</td>
<td>-0.01</td>
<td>1.9960</td>
<td>-0.42</td>
<td>-5.40</td>
<td>1.42</td>
</tr>
<tr>
<td>july</td>
<td>-0.84</td>
<td>2.48</td>
<td>0.06</td>
<td>1.91</td>
<td>4.43</td>
<td>-4.54</td>
<td>-0.01</td>
<td>1.8750</td>
<td>-0.40</td>
<td>-6.83</td>
<td>1.56</td>
</tr>
<tr>
<td>august</td>
<td>-0.52</td>
<td>4.56</td>
<td>0.06</td>
<td>4.62</td>
<td>9.24</td>
<td>-3.13</td>
<td>-0.02</td>
<td>3.2330</td>
<td>-2.25</td>
<td>-6.64</td>
<td>0.98</td>
</tr>
<tr>
<td>september</td>
<td>7.31</td>
<td>2.92</td>
<td>0.14</td>
<td>0.07</td>
<td>3.15</td>
<td>-2.00</td>
<td>-0.02</td>
<td>3.5510</td>
<td>-3.93</td>
<td>-6.51</td>
<td>1.93</td>
</tr>
<tr>
<td>october</td>
<td>1.12</td>
<td>2.91</td>
<td>0.55</td>
<td>0.71</td>
<td>4.17</td>
<td>-1.92</td>
<td>-0.01</td>
<td>3.3810</td>
<td>-2.12</td>
<td>-7.41</td>
<td>2.12</td>
</tr>
<tr>
<td>november</td>
<td>-0.56</td>
<td>2.16</td>
<td>0.21</td>
<td>0.92</td>
<td>3.20</td>
<td>-1.30</td>
<td>-0.01</td>
<td>3.8550</td>
<td>-0.71</td>
<td>-2.67</td>
<td>0.17</td>
</tr>
</tbody>
</table>

### Monthly Water Balance Zebrijanske Plavny

![Monthly Water Balance Chart](chart.png)

The water balance of SZP HYDRO as a bar chart.
5.5 The residence times

The residence time in the Plavny is of main interest for the ecological processes. It can be read directly from the water balance. The first three months are used to lose the influence of the initial conditions, so the volumes over these months are of illustrative value only. For the Stentsovsko Plavny, the total flow in the next few months is approximately 10 million m³, while the volume of the Plavny is 50 million m³. This gives a residence time of 5 months. For the months September-November the flow decreases to 3 million m³, so the residence time increases to 14 months. For the Zebrijanske Plavny, the total flow is approximately 5 million m³ against a volume of 30 million m³, giving a residence time of 6 months.

It should be noted that this residence time is an average for the entire Plavny. In the southern part of the Zebrijanske Plavny the residence time is certainly higher than 6 months, while in the northern part it is lower. Furthermore, the residence time in the reed beds is most probably higher than the residence time in the open water. The spatial variation of the residence times has not been determined, but this could be possible in the future, if accurate data of the salinity will be available.
6 Input for general simulations

The purpose of the water balance model SZP HYDRO is to evaluate the impact of different water management scenarios. The data of the field survey in 1997 gives a momentary impression of the hydrology of the Plavny. This is useful for a calibration of the model, but to evaluate the impact of water management longer time series are needed. Such time series have been collected partly from data available from the Institute of Water Management of the Southern Ukraine and partly from the Hydrometeorological Institute at Izmail. The available data is used to prepare synthetic input for a ‘dry year’, a ‘wet year’ and an ‘average year’.

6.1 Danube water levels

The water levels of the Danube are measured at Kilya. Over the period 1951-90 each year has been classified statistically by comparing the yearly averages. In this classification 1980 is a wet year with a probability of 7% on higher water levels; 1990 is dry with a probability of 93% on higher water levels and 1984 is average with a probability of 54% on higher water levels. The year 1997 turns out to be an average year for the Danube water levels, as shown in Figure 15.

![Danube water levels at Kilya](image)

Figure 15 The Danube water levels at Kilya
6.2 Black Sea water levels

The level of the Black Sea is measured at Primorsko. Over the period 1953-97 the monthly extremes are available and daily values were supplied of 1953, 1988 and 1997. The yearly maximal and minimal levels over this period are shown in Figure 16.

![Figure 16 The extreme Black Sea levels per year as measured at Primorsko](image)

The variation between minimal and maximal levels is approximately 1 meter. The water level of the Black Sea is mainly wind driven and there is hardly no tide. Wind driven levels vary on a time scale of days.

![Figure 17 The daily water levels at Primorsko for 3 different years](image)
The data shows that on the whole the Black Sea level was more or less constant during 1997 and 1988, having daily variations in the order of 1 dm. Compared to 1997, the 1988 shows more variation. The average Black Sea level for 1953 is much lower than the average level of 1988 or 1997 and the level also shows a seasonal variation. In this sense, 1953 can be marked as a ‘dry year’. The years 1988 and 1997 are comparable, although 1988 has more extreme water levels. In this sense, 1988 can be marked as a ‘wet year’.

The water levels of the Black Sea are compared to the measured water level at lock 4 in Figure 18.

![Black Sea levels comparison graph](image)

Figure 18 The water levels of the Hydrometeorological Institute compared to the levels of the IBSS

There is a difference between the levels, but it is less than 1 dm for the months April-August. The data is measured at different locations, so this can be explained from wind effects. For the months September-October the difference is 3 dm, which is very large. This may be an error in the water levels at lock 4. This is confirmed by the model results of Chapter 5, because in the Zebrijanske Plavny the simulated level decreases more slowly than the measured water level in September.

### 6.3 Drainage

The volumes of the pumping stations are available on a monthly basis. The annual volumes are given in the table below.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>volume</td>
<td>22.4 million m³</td>
<td>16.5 million m³</td>
<td>16.5 million m³</td>
<td>15.7 million m³</td>
</tr>
</tbody>
</table>
Each of the six pumping stations is allowed to pump a certain maximum volume into the Plavny. The sum of the maximal volumes is 40 million m$^3$/year. In reality, the volumes are bounded by economical restrictions. The maximum of 40 million m$^3$/year is never reached because the irrigation authorities do not have the budget to cover such an expense on electricity. The drainage volume is constant in the last three years. The year 1994 is a ‘wet year’ compared to 1995-97.

The drainage water from the Fisher economy is minor and there is no restriction on this pumping station. The annual volume is approximately 3 million m$^3$/year.

### 6.4 Precipitation

The average precipitation over 1951-86 is available from the meteorological station at Vilkovo. The precipitation as measured in 1997 by the station near the Hunter economy is above average. The precipitation is exceptionally high in August 1997.

![Precipitation](image)

The monthly rainfall of a few years is contained in the table below. The table shows that 1997 was an exceptionally wet year. Even for an average rainfall in August, the yearly precipitation of 1997 is more than 100 mm above average.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>rainfall (mm)</td>
<td>556.3</td>
<td>549.4</td>
<td>303.9</td>
<td>320.1</td>
<td>508.3</td>
<td>491.1</td>
<td>635.0</td>
<td>447.4</td>
</tr>
</tbody>
</table>

### 6.5 Evapotranspiration

The evapotranspiration is measured by the meteorological station at Vilkovo. The yearly average and its standard deviation are available. This statistical information has been converted to wet year and a dry year, as presented in the table below.
Table 12

<table>
<thead>
<tr>
<th>Evapotranspiration</th>
<th>dry year</th>
<th>average</th>
<th>wet year</th>
</tr>
</thead>
<tbody>
<tr>
<td>yearly amount</td>
<td>875 mm</td>
<td>742 mm</td>
<td>625 mm</td>
</tr>
</tbody>
</table>

The evapotranspiration during the 8 month survey period of April-November 1997 was 701 mm, so in this respect 1997 was a relatively dry year.

6.6 Synthetic data for a dry year and a wet year

The data in the preceding sections has been used to prepare synthetic dry years and wet years, as presented in Table 13.

Table 13

<table>
<thead>
<tr>
<th>Data</th>
<th>Dry year</th>
<th>Average year</th>
<th>Wet year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Danube level Kilya</td>
<td>1990</td>
<td>1997</td>
<td>1980</td>
</tr>
<tr>
<td>Black Sea level Locks 4 and 5</td>
<td>1953</td>
<td>1997</td>
<td>1988</td>
</tr>
<tr>
<td>Drainage</td>
<td>1997</td>
<td>1997</td>
<td>1994</td>
</tr>
<tr>
<td>Precipitation</td>
<td>1990</td>
<td>average from data 1951-90</td>
<td>1997</td>
</tr>
<tr>
<td>Evapotranspiration</td>
<td>from statistical analysis</td>
<td>average from data 1951-90</td>
<td>from statistical analysis</td>
</tr>
</tbody>
</table>

The scenario computations in the next chapter are carried out for the average year. Table 14 contains the concentrations which were used for the salt balance in these computations. These concentrations are only indicative and were not taken from measurements.

Table 14 concentrations in SZP HYDRO

<table>
<thead>
<tr>
<th>Salt concentration</th>
<th>mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>BlackSea</td>
<td>2000</td>
</tr>
<tr>
<td>Danube drainage</td>
<td>0</td>
</tr>
<tr>
<td>Stentsovsko drainage</td>
<td>25</td>
</tr>
<tr>
<td>Stentsovsko drainage/fishponds</td>
<td>600</td>
</tr>
<tr>
<td>precipitation</td>
<td>100</td>
</tr>
<tr>
<td>upwelling</td>
<td>0</td>
</tr>
<tr>
<td>Sasik channel</td>
<td>10</td>
</tr>
<tr>
<td>mg/l</td>
<td>50</td>
</tr>
</tbody>
</table>
7 The impact of several water management scenarios

The input for the simulations in this chapter is the 'average year' described in chapter 6.

The Plavny is surrounded by dams and there are locks at the inlets and outlets. This is a regulated wetland. At the moment, there is no definite water management plan. Lock Tupikovy is opened if more water is needed in the Plavny and it is closed if water is flowing out of the Plavny into the Mezcolhozny channel. However, the lock is hardly ever fully opened nor is it hardly ever fully closed. The same was true for Locks 4 and 5 until recently, in January 1998, DPA opened the shutters in the locks which so far were jammed shut. During a field trip of 8 and 9 April it appeared that the water levels in the Zebrijanske Plavny were very low, at approximately zero level. Ecological interpretations apart, this indicates that a different water management can make a big difference for the hydrology of the Plavny. This is confirmed by the model results in this chapter.

Jedema (1996) has studied various possible water management options for the Plavny. In particular he has recommended the following scenario’s:

1. The marginal wetland. All the locks are always open.
2. The springflood riverrine wetland. The Tupikovy lock is opened if the level in the Mezcolhozny channel is above the level in the Stentsovsko Plavny, otherwise it is closed. Locks 4 and 5 are always closed.
   A variation of the springflood riverrine wetland is that Locks 4 and 5 are opened if the Tupikovy lock is open.
3. The springflood estuarine wetland. Same as 1 for the Tupikovy lock, but now Lock 4 and 5 are open if the Black Sea level is above the level in Zebrijanske Plavny. This option may lead to salt intrusion.
   A variation of the springflood estuarine wetland is that Locks 4 and 5 are always open.

SZP HYDRO has been developed so that it can model these and other water management scenarios. At a structure it is possible to open/close it all the time, or open/close it if the level in one of the compartments is higher than the other, or open/close it if a trigger level is reached. Furthermore it is possible to define time controllers or to define a different size of the structure.

The model results for the three scenario's are exhibited below for different output parameters. No definite conclusions are drawn as this is the job of the ecological experts who have a better understanding of the area. Apart from the total water balance the following results are of interest: water levels to study the inundation of the reed beds; residence times to study the effect of the water management on ecological processes; the salt balance to study the effect of intrusion of Black Sea water.
7.1 The marginal wetland

The purpose of the marginal wetland is to increase the water flow through the Plavny as well as the variation of the water level. To achieve this all locks are fully opened all the time. In fact, DPA fully opened lock 4 and 5 in January 1998, so that the marginal wetland scenario is now being implemented for the Zebrijanske Plavny.

The water balance and the salt balance

The resulting water balance is shown in Figure 15.
Figure 15 The water balance for the marginal wetland

The balance shows large exchange volumes at the Tupikovy lock. Sometimes the flow is directed into the Stentsovsko Plavny, sometimes it is directed out of the Plavny. This depends on the level of the Danube. The balance for the Zebrijanske Plavny shows a constant flow from siphon 1 to locks 4 and 5. The exchange volumes are smaller for the Zebrijanske Plavny, because siphon 1 only allows a limited discharge.

The salt balance is contained in Figure 16. The salt balance in the model has not been calibrated, so the balance is indicative only.
The salt balance shows that there is salt intrusion from the Black Sea in March, October and November, even though at locks 4 and 5 the direction of the flow is mainly outwards of the Plavny. Occasionally there is inflow from the Black Sea and because of the high salinity of the sea water, there is a net salt inflow through the locks even though there is a net water outflow. That is why the salt balance in the Zebrijanske Plavny shows much higher loads. The main salt load in the Stentsovsko Plavny is imported by the drainage water.

**the water levels and the salinity**

The computed water levels are shown in Figure 16, which also shows the measured water levels at the boundary of the Plavny. Recall that Kilya is upstream of the Mezcolhozny channel, so the water levels are higher there than they are at the Mezcolhozny lock.
Figure 16 The computed water levels for the marginal wetland

For the marginal wetland, the water levels are different compared to the current situation, as described in Chapter 5. For the Stentsovsko Plavny the water level follows the level of the Danube and shows more variation than the current water level. For the Zebrijanske Plavny the water level follows the level of the Black Sea and is much lower than the current water level. This was confirmed by a field trip in April 1998. Currently locks 4 and 5 are opened and the water level in the Zebrijanske Plavny is very low, around 0 m in the Baltic system.

To illustrate that the limited discharge through siphon 1 is a serious constraint, Figure 17 shows the water level in the Plavny if the model discharge coefficient of the siphon is set equal to the measured discharge coefficient (= 'maximal capacity').
Figure 17 The water level in the Zebrijanske Plavny for the measured discharge coefficient at siphon 1.

The water level increases on average by 1 dm in the Zebrijanske Plavny while it decreases by 1 dm in the Stentsovsko Plavny.

The salinity for all compartments in the water balance model is shown in Figure 18.

Figure 18 The salinity in the Plavny.

This result is only indicative since the salt balance has not been calibrated and neither is the exchange between open water and reed bed. The salinity in the Zebrijanske Plavny increases for the open water and an equilibrium is not yet reached at the end of the year. The chloride concentration increases in one year to 10 g/l for the open water. The equilibrium is almost at 20 g/l, which is the estimated salinity of the Zebrijanske Bay. For the reed bed there is a delay because of the limited exchange with the open water.
Residence times and response times

The residence time in the marginal wetland scenario is slightly shorter than in the current situation, because there is a higher exchange volume through the Tupikovy lock. The difference is only minor.

The response time of the open water in the Zebrijanske Plavny to variations of the Black Sea level is almost instantaneous. The response time of the Stentsovsko Plavny to variations of the Danube level is in the order of a week.

conclusion

In the marginal wetland scenario the Stentsovsko Plavny and the Zebrijanske Plavny get very different hydrological characteristics. The exchange volumes increase compared to the water balance of 1997, but the exchange volume through siphon 1 does not increase much. In this scenario, the Stentsovsko Plavny follows the variation of the Danube and the Zebrijanske Plavny follows the variation of the Black Sea. If siphon 1 reaches its maximal capacity (= measured discharge coefficient), then the Zebrijanske Plavny imports much more water from the Stentsovsko Plavny, but still there is a distinction between the two Plavnys.

7.2 The springflood riverrine wetland

The purpose of the riverrine wetland is to increase the water levels in the Plavny. To achieve this the Tupikovy lock is opened if the Danube level is higher than the level in the Plavny. Locks 4 and 5 are closed all the time to prevent outflow. Another variant is to open locks 4 and 5 if the Tupikovy lock is open, to prevent the water from getting trapped in the Zebrijanske Plavny.
The water balance and the salt balance

The water balance for this scenario is shown in Figure 19 for closed locks 4 and 5.

Figure 19 The water balance for the springflood riverine wetland

The water balance shows that the exchange volumes are significantly smaller than for the marginal wetland scenario. For the Stentsovsko Plavny there is an inflow at the Tupikovy lock. This is compensated by an outflow through siphon 1 and by evapotranspiration. In the Zebrijanske Plavny there is inflow through siphon 1 which compensates the water loss by evapotranspiration.
The result for the other variant (opening locks 4 and 5 if the Tupikovy lock is open) is shown in Figure 19b.

Figure 19b The water balance for the springflood riverine wetland under the option of opening locks 4 and 5.

In this variant the water balance does not change much for the Stentsovsko Plavny, but the balance does change for the Zebrijanske Plavny, because there is an outflow through locks 4 and 5.

The salt balance is given in Figure 20 for the closed locks 4 and 5.
Figure 20 The salt balance for the spring flood riverine wetland if locks 4 and 5 are closed

The balance shows that the salinity increases because the relatively saline water from the pumping stations is collected in the Plavny because the natural outlets 4 and 5 are closed. The salt balance for the option of opening locks 4 and 5 simultaneously to the Tupikovy lock is shown in Figure 21. It shows that there is salt intrusion of the Black Sea.
Figure 21 The salt balance for the springflood riverrine wetland if locks 4 and 5 are opened

The salt balance shows that now the salt is not trapped in the Plavnys, because there is an outflow to the Black Sea through locks 4 and 5.

**The water levels and the salinity**

The water levels under this management scenario are given in Figure 22. The figure confirms that under this scenario the levels are higher than the current water levels.
Figure 22 The computed water levels in the Plavny under both management options of locks 4 and 5

The figure shows that the water first leaves the Zebrijanske Plavny when locks 4 and 5 are open and then the water flow from the Stentsovsko Plavny fills the Zebrijanske Plavny again.

The salinity is given in Figure 23. The salt concentrations increase under both management options in the reed beds. This happens because the sources of the salinity, the pumping stations, pump the drainage water into the reed beds. The drainage water stays in the reed beds because the exchange between open water and reed beds is small in this scenario. If the locks 4 and 5 are closed, the water is just collected in the Plavny and this restricts the exchange between open water and reed beds. If there is an outflow through locks 4 and 5, then some of the water leaves the reed beds and enters the open water. However, there is a simultaneous inflow of Danube water through the Tupikovy lock which quickly substitutes the water that has flown out. Again restricting the exchange between open water and reed beds.
The residence time and the response time

Compared to the marginal wetland scenario, the residence times in the springflood riverrine wetland increase. The residence time for both Plavny increases to approximately 8 months if it is computed as the quotient of the total water volume and the exchange volumes per month. In fact, if locks 4 and 5 are closed, the water only leaves the Plavny by evapotranspiration so the residence time is infinite. If the locks are opened, then the residence time decreases to approximately 5 months.

The response time of the Zebrijanske Plavny is illustrated by the water level variations under the option of opening locks 4 and 5 in Figure 22. The response of the Zebrijanske Plavny by the outflow to the Black Sea is almost instantaneous. The response by the inflow through siphon 1 is approximately one month.
conclusion

The goal of this scenario, higher water levels, is achieved fully. The water levels in the Plavny increase significantly, both for the Zebrijanske and the Stensovsko part. The scenario leads to very high residence times if locks 4 and 5 are closed, which may not be acceptable from an ecological viewpoint. If the locks are opened simultaneously to the Tupikovy lock, the residence times are shorter, although never as short as for the marginal wetland scenario.

7.3 The springflood estuarine wetland

The purpose of the springflood estuarine wetland is similar to the springflood riverine wetland. The management of the Tupikovy lock is the same as in the springflood riverine wetland. Again there are two options for locks 4 and 5 in this scenario. The first option is that locks 4 and 5 are opened to let in water from Zebrijanske Bay, if the level there is higher than in the Zebrijanske Plavny. The second option is that locks 4 and 5 are always open. The purpose of the first option is to let in salt water from the Black Sea. In practice, this does not work because the water levels in the Zebrijanske Plavny is much higher than the water level in the Black Sea. This is illustrated by Figure 22 for the option of keeping locks 4 and 5 closed. The simulation results for option 1 of salt water inlet in this scenario are exactly the same as the simulation results for option 1 of keeping the locks closed in the previous scenario. Therefore we only give the results for option 2, in which the locks are always open.

The water balance and the salt balance

The water balance is shown in Figure 24.
Figure 24 The water balance for the springflood estuarine wetland

The water balance is comparable to the water balance for the marginal wetland, only now there is no outflow through the Tupikovy lock, no inflow. The water balance shows a continuous flow from the Tupikovy lock, through siphon 1 and out of the Zebrijanske Plavny through locks 4 and 5. Just like in the marginal wetland scenario.

The salt balance is shown in Figure 25.
The salt balance confirms that this scenario is very much like the marginal wetland scenario. There is salt water from the Black Sea even though the dominant direction of the flow is outwards through locks 4 and 5. Since the results are so similar to the marginal wetland scenario, the other output parameters are not discussed.

**Conclusion**

The springflood estuarine wetland scenario does not give results which are much different from the other scenarios. There are two options in this scenario. Under option 1, opening locks 4 and 5 if the Black Sea level is higher than the water level in the Plavny, the results are the same as for the springflood riverine wetland because in practice locks 4 and 5 are closed simply because the Black Sea level is never higher than the level in the Plavny. Under option 2 the results are similar to the marginal wetland, only there is no outflow through the Tupikovy lock, only inflow.

**7.4 Conclusions from the management scenarios**

The model simulations show that a different management will enforce different hydrological conditions. In the marginal wetland, the flows increase and the residence times are relatively low. In the springflood scenarios, the water levels increase and the residence times are relatively long. The choice of the optimal management scenario is up to the ecological experts.

The model simulations confirm that siphon 1 seriously hampers the flow from the Stentsovyko part to the Zebrijanske part. Management options aside, an increase of the flow through siphon 1 will probably be good for the ecological conditions in the Zebrijanske Plavny.

The results on the salt concentrations show that the reed beds may have a different salinity and different residence times from the open water. This has not been calibrated, however, so
the model results are only indicative. Since the reed beds are important filters of the water, reed is known to filter pollutants, a future model calibration on this part would be helpful for the ecological evaluation.

The water levels of all scenario’s are compared in the figures below.

**Water level in Stentovsko Plavni**

**Water level Zebrijanske Plavni**

Figure 26 The water levels for the different scenarios
8 Conclusions and recommendations

8.1 Conclusions

Conclusions from the model simulations of the water management options

It is possible to regulate the water level in the Plavny in different ways, getting higher water levels, or a larger variation of the water levels, or larger exchange volumes. This is possible mainly because of the variation of the water levels on the Danube, which can be used to give large exchange volumes or to increase the water inlet through the Tupikovy lock. Also the locks 4 and 5 strongly regulate the water levels of the Zebrijanske Plavny.

At present, the water management of the wetland is incidental. The management of the Tupikovy lock, for instance, depends on the operation of the pumping station at the end of the Mezcolhony channel. Furthermore unauthorised personel tamper with the shutters. These are mainly recreational fishermen who occasionally close the Tupikovy lock.

The Black Sea level is mainly wind driven, there is hardly any tide. Most of the time the water level is lower than that of the Plavny and locks 4 and 5 can only serve as outlets. Occasionally, under storm conditions the water level in the Black Sea is sufficiently high to let the water into the Plavny. Such an inlet will increase the salinity in the Zebrijanske Plavny to a few grammes per liter.

The marginal wetland scenario increases the flow through the Plavnys, decreasing the residence times to a few months. The springflood scenarios increase the water levels in the Plavnys and the residence times also increase. In the springflood scenarios the residence times depend on the management of locks 4 and 5, which are the only outlets in these scenarios. If the locks are constantly closed, the residence time is infinite. If the locks are opened, the residence time is in the order of half a year.

More accurate information on the residence times in the open water and the reed beds can be obtained if the model is calibrated on the salt balance.

Conclusions from the field data

The most important conclusion from the field data is that there is a consistent spatial variation of the water levels in the Zebrijanske Plavny. There is a downward gradient from west to east. This gradient can be explained from a constant flow in the Plavny from the siphon under the Sasik channel through the Dzebrianovski Lake to the Black Sea. The water flow does not reach the southern part of Zebrijanske Plavny, which has no direct connection with the siphon. The absence of a consistent water flow may explain why the southern part of the Zebrijanske Plavny is deteriorating most rapidly.
The processing of the data of the field survey showed that there may be a measurement error in the water levels at Locks 4 and 5. This error can only be explained from an error in the benchmark in the church of Primorskoe. It is advisable to measure the benchmark once more by levelling from the nearest benchmarks of the Ukrainian Land Survey Service. However, a possible error in the water levels has no consequence for the main conclusions of this study.

The model results were obtained based on data supplied by Mr Egorashenko and by the Hydrometeorological Institute in Izmail. Four different input files were prepared: a wet year, a dry year, an average year and the year 1997. The average year was used in the scenario simulations. More information can be obtained from further computations with the other input files.

8.2 Recommendations

The findings of this study lead to the following list of suggestions for future study or future operations in the Plavny

Further development of the model SZP HYDRO

- **SZP HYDRO** should be used to estimate the effect of worst case scenario’s, based on dry years or wet years. The model input is available.
- The model should be calibrated on the salt balance to get a better estimate on the water flow between open water and reed beds.
- The model can be extended for nutrient and pollutant balances, using first order decay/growth terms to model the ecological and the chemical processes.
- The model produces water levels and not water depths, which are more important for an ecological assessment. To produce water depths, a GIS map of the Plavny is required.

Recommendations on water management

- At present, the management of the Tupikovy lock depends on the management of the pumping station in the Mezcolhozny channel. The priority of the Tupikovy lock should be the management of the Plavny. An investment is recommended in the capacity of the pumping station, so that it does not depend on the water level of the channel.
- The water management of the Plavny should be centralized and a well defined management should be prepared.
- A simple device (some kind of lock) can guard the Tupikovy lock and locks 4 and 5 against the use of unauthorised personnel.
- It is advisory to increase the flow through siphon 1 by dredging the channels in the Zebrijanske Plavny. In particular, it is useful to improve the connection of the channel south of the siphon to the old rivers through the Plavny.
- An alternative to the previous suggestion is a second siphon under the Sasik channel, connecting the southern part of the Zebrijanske Plavny to the Stentsovsko Plavny. This will also improve the water flow, but it is probably more expensive.
Further measurements and data

- A more detailed measurement of the bathymetry (GIS map) is essential for a good evaluation of the water balance results.
- The hydrodynamical conditions in the Plavny can be studied by a tracer experiment in which dye is injected near siphon 1. In this way the hydrodynamics of the Zebrijanske Plavny can be monitored. Tracer experiments will give an insight in the residence times for various parts of the Plavny and also in the exchange between open water and reed beds. In this way it is also possible to verify that there is no leakage from siphon 1 to the Sasik channel, as was suggested in (Van der Vat, 1997).
- The salt balance in the model can be calibrated if some measurements are made of the spatial and the temporal variation of the salinity. In this way the exchange of water between the reed beds and the open water can be calibrated in the model. The residence time in the reed beds and in the open water may be different and this may have consequences for the water quality in the Plavny.
- The level of the benchmark in Primorskoe church should be measured. More data can be obtained from Mr. Egorashenko and from the Hydrometeorological Institute in Izmail. In particular, information on the volumes of the pumping station at the end of the Mezocolhozny channel is needed.
- Divers should be installed for continuous registration of the water levels at the locks, for instance at both sides of siphon 1, for more information on the hydraulic conditions and on the water levels across the Plavny.
9 References


A Technical reference SZP HYDRO

The water balance model SZP HYDRO is a special EXCEL® application and it can be operated with a working knowledge of EXCEL. It runs under WINDOWS 95® under EXCEL version 7. The model is contained in the file BALANCE.XLS and it can be run by loading that file into EXCEL.

All macros in EXCEL are programmed in the object oriented VISUAL BASIC language. The EXCEL language itself is modular, so the SZP HYDRO model satisfies the current standards for maintenance of computer programmes.

There are two versions of SZP HYDRO, a user version and a programmer version. In the user version not possible to extend the models functionality, because the worksheets are hidden. This model version is guaranteed by DELFT HYDRAULICS and errors will be repaired. In the programmer version it is possible to change the functionality of the model. The worksheets are unhidden, so the model can be adapted to the programmer’s preference.

The file handling of the model is represented in a flow chart:

```
User defined input .XLS file
[format of the file according to example file 1997.XLS]

Input of boundary conditions

Model file BALANCE.XLS
[this file should ALWAYS be opened first!]

Output of monthly volumes and daily water levels

Output file SZP_OUT.XLS
[contains the model results + parameter input]
```

Input

The user opens the file BALANCE.XLS. By clicking the button SELECT YEAR FOR ANALYSIS he can choose the input file for his simulation. The standard input files are 1997.XLS, AVERAGE.XLS, DRYYEAR.XLS and WETYEAR.XLS. Some of the data in these files is for model input [contained in the columns marked as PARAMETER]. This is essential information. Some of the data is for output only and represents measured data [contained in the columns marked as DATA]. This information is not essential and may be omitted. The user may prepare his own input files, as long as they are in the same format as these example input files.
Simulation

The user click the button MANAGEMENT OF LOCKS AND EDIT PARAMETERS. The worksheet 'management' is opened and the user modifies the management of the locks. By clicking on EDIT PARAMETERS in this worksheet, the worksheet 'parameters' is opened. The parameters are: the size of the locks, the discharge coefficients, trigger levels for the Plavny, the bathymetry and the chloride concentrations. Once the management and the parameters are set, the user returns to the main sheet by clicking the RETURN button. On the main sheet the user may now click CALCULATE. The model computes the new water balance. On a standard PENTIUM® 120 Mhz this takes a few minutes. The end of the computation is signalled by a beep.

The model output

The model output contains the water balance, the salt balance, water levels and concentrations, displayed in graphs and tables, represented in the output file SZP_OUT.XLS. By clicking OUTPUT IN TABLES AND GRAPHS this spreadsheet is opened and information from BALANCE.XLS is copied into this spreadsheet. Once the computation is satisfactory, the user stores SZP_OUT.XLS simply by choosing the SAVE FILE option in EXCEL, so the user does his own file management. It is a stand alone file and it can be saved under a user defined name.

SZP_OUT.XLS contains the parameter input and the management options chosen by the user. In this way the settings of the computation can be restored.

The user may adapt SZP_OUT by adding or deleting graphs, changing colors or formats. If the adapted SZP_OUT is saved in the same directory as BALANCE, the model output will be presented in the adapted format.
Russian technical reference

Модель водного баланса SZP HYDRO является специальным EXCEL® приложением и не требует дополнительных знаний программы EXCEL. Приложение работает в среде WINDOWS 95® в EXCEL версии 7. Модель содержится в файле BALANCE.XLS и исполняется путем загрузки файла в EXCEL.

Все макросы EXCEL запрограммированы в объектно-ориентированном языке VISUAL BASIC. Язык EXCEL сам по себе достаточно известен, так что модель SZP HYDRO удовлетворяет нынешним стандартам по обслуживанию компьютерных программ.

Имеются две версии SZP HYDRO: пользовательская версия и программируемая версия. В пользовательской версии нельзя расширить функциональные возможности модели, потому что рабочие таблицы скрыты. Эта версия модели гарантирована DELFT HYDRAULICS и возможные ошибки будут устранены. В программируемой версии изменение функциональных возможностей модели допускается. Рабочие таблицы в ней не скрыты, так что модель может быть адаптирована по желанию.

Файл обработки модели представлен на следующей диаграмме:

<table>
<thead>
<tr>
<th>Ввод пользователя из .XLS файла</th>
</tr>
</thead>
<tbody>
<tr>
<td>[формат файла в соответствии с примерным файлом 1997.XLS]</td>
</tr>
<tr>
<td>Ввод начальных условий</td>
</tr>
<tr>
<td>Файл с моделью BALANCE.XLS</td>
</tr>
<tr>
<td>[эти файл должен быть ВСЕГДА открыт первым!]</td>
</tr>
<tr>
<td>Вывод ежемесячных объемов и дневной воды</td>
</tr>
<tr>
<td>Файл вывода SZP_OUT.XLS</td>
</tr>
<tr>
<td>[содержит результаты модели + входные параметры]</td>
</tr>
</tbody>
</table>

Ввод

Пользователь открывает файл BALANCE.XLS. Путем нажатия кнопки SELECT YEAR FOR ANALYSIS он может выбрать файл ввода для симуляции. Стандартные файлы ввода 1997.XLS, AVERAGE.XLS, DRYYEAR.XLS и WETYEAR.XLS. Некоторые данные из этих файлов являются входными данными модели [содержатся в колонках с пометкой PARAMETER]. Это важная информация. Некоторые данные служат только для вывода и представляют измеренные данные [содержатся в колонках с пометкой DATA]. Эта
информация не столь важна и может быть опущена. Пользователь может заготовить свои собственные файлы ввода, если они имеют тот же самый формат как и примерный файл ввода.

Симуляция

Пользователь нажимает кнопку MANAGEMENT OF LOCKS AND EDIT PARAMETERS. Рабочая таблица ‘management’ открывается и пользователь изменяет управление шлюзами. Посредством нажатия кнопки EDIT PARAMETERS в рабочей таблице, рабочая таблица ‘parameters’ открывается. Параметрами являются: размер шлюзов, коэффициенты расхода, уровень включения для Плавней, батиметрические данные и концентрация хлорида. После того, как управление и параметры установлены, пользователь возвращается в главную таблицу путем нажатия клавиши RETURN. В главной таблице пользователь может нажать кнопку CALCULATE. Модель вычисляет новый водный баланс. На стандартном PENTIUM® 120 МГц процесс занимает несколько минут. Окончание вычислений подтверждается звуковым сигналом.

Выходные данные модели

Выходные данные модели содержат водный баланс, солевой баланс, уровни воды и концентрации, изображенные на графиках и таблицах и представленные в файле результатов SZP_OUT.XLS. После нажатия кнопки OUTPUT IN TABLES AND GRAPHS открывается соответствующая рабочая таблица, в которую копируется информация из BALANCE.XLS. Если результаты вычислений удовлетворительные, то пользователь записывает их в SZP_OUT.XLS посредством выбора опции SAVE FILE из меню EXCEL. Таким образом пользователь сам производит организацию файлов. SZP_OUT.XLS является независимым файлом и может быть записан под любым именем указанным пользователем.

SZP_OUT.XLS содержит входные параметры и опции управления выбранные пользователем. Таким образом установки вычисления могут быть восстановлены.

Пользователь может адаптировать SZP_OUT посредством добавления или удаления графиков, изменения цветов или форматов. Если измененный SZP_OUT записан в том же каталоге, что и BALANCE, то выходные результаты модели будут представлены в адаптированном формате.