HYDROLOGICAL REGIME OF BEVERLY SWAMP

CONTENT

INTRODUCTION

In order to establish the hydrological regime of Beverly Swamp the available geological, morphological and bibliographical information and observed data obtained during last 30 years was summarized. In the very first approach the available data allows to create the month water balance model using an area-separation method. On the base of obtained water balance the water storage – outflow model was made also using the method of usable storage coefficient developed by author.

AREA-SEPARATION METHOD

Peat land is the nature complex system characterized by existing of the organic material, peat with depth from 30 cm, saturated by water and has specific water loving vegetation (Chebotarev, 1978).

Area separation of any peat land system is based on the statement that each homogeneitive part of the examined peat land has its own vegetation, surface microrelief and physical features of its active layer. Such a homogeneitive part is called the microlandscape. The similar microlandscapes have similar hydrological features and vice versa the different microlandscapes have different features. Very often the area separation method is applied for association or unification of separated areas in order to obtain hydrological features for them (Smith and all, 1999). The same way is used for the Beverly Swamp water balance and water storage-outflow models composition.

I. GENERAL INFORMATION ABOUT BEVERLY SWAMP

Presented here general information has conclusive temper due to it has been already selected to fit the area-separation method.

I.1 ABOUT THE SITE

Beverly Swamp is an 8.4 km² forested wetland located northwest of Hamilton, Ontario (42°22'N, 80°07'W) (Welch, 1978). It is a typical temperate Southern Ontario swamp that has woody vegetation, is flooded twice a year, and has no standing water in mid to late summer (http://www.cciw.ca/green-line/wildlife/glwcap/intro.html).

The Swamp is within the Spencer Creek watershed. Spencer Creek drains a watershed dominated by calcareous bedrock, and from 1960 its flow has been regulated by Valens reservoir which is upstream of Beverly Swamp. Peak discharges in spring and fall. Water also enters the Swamp by Fletcher creek and many other small streams, which dry up over the summer period. The whole Swamp area is surrounded by mixed agricultural land.

I.2 HISTORY

Beverly Swamp is the largest temperate wetland in southern Ontario and is in an agricultural area (Crook, 1999). It was also known as Westover Bog during presettlement times. Much of the swamp was the result of flooding due to beaver dams throughout the township, many of which were drained during the early part of the 19th century for valuable farmland.

Clearing of the land for agriculture and lumbering continued until about 1910 when most of useful land was occupied (Welch, 1978). More recently (1940s) there was an interest in selling peat from the Swamp for horticulture. At this time further tree felling and excavation of peat took place in the southern part of the Swamp; ponds remain where the peat was removed. It was recommended in 1960 that a flood control reservoir be built at Valens; this has since been constructed and has significantly altered the hydrology of the Swamp by lowering summer flow and increasing flow in spring and fall when large amounts of water are released from the reservoir. Changes in water table have lead to longer-term changes in the forest composition. The vegetation of the Swamp has been affected more directly and drastically by Dutch elm disease; this disease has killed most of the larger trees of white elm, a species which until recently played a major role in the forest communities of swamps in southern Ontario (Welch, 1978).

I.3 LANDSCAPE

Surrounding topography is rolling by elevations from 250 to 285 m above sea level. The margins of the swamp era at 265 m. Topography is determined by the thickness of glacial deposits such as drumlins, till plains and terminal moraines. The Galt Moraine bounds Beverly Swamp to the south, on the north by the sands and silts of glacial Lake Warren, on the east by the Niagara Escarpment, and on the west by moraines of Horseshoe Formation (fig.1, Valverde, 1978).

Spencer Creek is dammed and regulated by Valens Reservoir upstream of the swamp. Once in the swamp, it branches out and 'disappears' as channeled flow for about 1 km, reappearing again downstream. Fletcher Creek originates outside of the swamp, from the northeast, and flows in a well-defined channel until it joins with Spencer Creek (Crook, 1999).

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I.4 GEOLOGY

Beverly Swamp morphometrically is divided into three approximately equal parts (fig.1): North part – 2.98 km², Central – 2.83 km² and South part – 2.6 km² (see the map). The Central part is the mostly explored and presents the meeting place for Spencer and Fletcher Creeks. Bifurcation of Spencer Cr. is observed in the west side of Central Part. North and South parts of the swamp are very similar in hydrologic point of view due to the same relations with flowing streams in theirs lowest parts, which are caused by geological conditions.

Spencer Creek Basin lies above the Niagara Escarpment and is underlain by Silurian formations, which rest uncomfortably upon Precambrian rock of igneous and metamorphic origins. The Palaeozoic beds dip gently southwestwards (5.3 m/km) to form a cuesta (Valverde, 1978). The thickness of glacial deposits and such glacial forms as drumlins, till plains and terminal moraines determine topography. 10,000 years ago Beverly Swamp was a glacial lake which has matured by euthrophication and bog succession to the current wetland (Crook, 1999).

Bore holes made in 1974 by Ontario Hydro enabled the construction of two profiles across the Swamp (fig.2). The profiles show two bedrock depressions (5-7m) of widely differing sedimentary characteristics. The southern depression (South part of the swamp) is attaining a greater depth. There is the Central Part of the swamp in northern depression.

Stratigraphically, the records show three phases in Swamp deposition (see the profile):
The bottom layer fines upwards showing both glacial and lacustrine retreats.
A series of layers coarsening upwards (in the most southerly depression only) may have resulted from a transgression during glacial retreat.
The upper and most recent deposits consist of layers of organic muck [1], gyttja[2] and marl[3] (Valverde, 1978).

Analysis of the western and eastern profiles shows that surface and bottom slopes of depressions do not coincide: surface slope has down trend to the west, bottom – to the east as well as creeks flow. The eastern boarders both of depressions are bedrock exits covered by thin layer of marl. Next very significant point is the peat is underlying by very thin uncompleted layer of marl after that there are sand, gravel sand and silt sand in the South part and homogeneitive silt sand in the Central one. It seems the depressions are the former terrace valleys filled by moraine deposits and those deposits have opposite slope than creeks. Even the profiles show that “western hole” in central part has a little bit lower elevations than eastern site of this part.

So, Beverly swamp is a huge triple sink covered by sponge, which intercepts runoff from river to the swamp due to its surface slope (see details in the INFLOW section of the water balance) and spend it for evapotranspiration and evaporation.

I.5 SOIL TYPE

The depth of peat within observed sites varies from one to five feet. The peat typically shows a 75% organic content (Woo, 1977). It is well-humidified woody, coarse, fibrous peat in a matrix of amorphous granular material (highly decomposed, finely divided plant fragments).
Peat depths are, on average, 37 cm at the Fletcher Site (very south edge of the North part and the northern edge of the Central part of the Swamp) and 88 cm at the Tower Site (west of the Central part). At the Spencer Site (north-west of the Central part) peat depths are consistently 150 cm (Crook, 1999). The first number is very underestimated if take it for the North part as whole. The measurements were done not far than 50 m from stream (Fletcher) where depth of peat should be smallest (Bogoslovsky and all, 1984). The third number is overestimated due to specific place: ‘western hole’ of Central part – the former lake. The most reliable number for whole swamp is 70-80

cm that combines very well with the profiles information. The profiles show 70-80 cm of peat in the South and about 60 cm in the Central part of the Swamp. Very similar data are given by Munro (1982, 1984). He took average depth amounts 85 cm. Actually, for water balance it is significant to know the active layer depth not whole peat deposit. There is the basic imagination of the active layer of peat land in figure 3. The upper boarder of active layer is the surface of peat land. The bottom boarder of the active layer is the long-term average of the year lowest water table level. According to former Soviet hydrological school (Bogoslovskiy and all, 1984) the following parameters should be the hydrological features of any wetland microlandscape: Kz = f(Z), Ko = f1(Z), q = f2(Z) and c = f3(Z), where Kz is the coefficient of filtration in active layer as the function of depth, cm/s, Ko – the average coefficient of filtration in filtrating layer (Zo –Z) , cm/s, q – water discharge from filtrating layer (Zo-Z), m^2/d, and c – specific yield as a function of depth (Z).

In this particular work the specific yield is the only parameter that is used for water balance. Specific yields for the three sites are very different also. The upper 50cm layer peat at the Fletcher Site has specific yield 9-15%, Spencer Site – 23-31% and Tower Site 5-7% coincidentally. It proves once more that Central Part is not homogeneitive, because both Spencer and Tower Sites locate in Central Part. Spencer site indicates former lake and Tower site – its bank. There is taken into account in the balance calculations: the area of the former lake is taken as large as 0.7 sq.km (0.083 from whole swamp area).

Different microlandscapes have different parameters, but the same microlandscapes have practically the same parameters despite of dissimilar locations. It is interesting that the active layer for *the pine-shrub microlandscape* (most similar to Beverly Swamp – a *minerotrophic cedar-deciduous swamp*, Munro, 1984) amounts up to 70 cm (Ivanov, 1975, Bogoslovsky, 1984). Beverly Swamp in North, South and East Central parts has the active layer 65 cm (see table 6). The depth of active layer amounts the average lowest level of the water table (Bogoslovskiy and all, 1984). Actually Beverly Swamp's peat deposit exceeds its active layer only 15-20 cm (85 cm, Munro, 1982,1984).

I.6 VEGETATION

According to Holladay's (1937) classification, Spencer Creek Basin Falls within the Great lakes – St. Lawrence Forest Region, Huron – Ontario Section. Vegetation has been investigated in detail in the Central and South parts of the Swamp (Welch, 1978). In the South part, there are red maple (53% of the basal area and 1700 per ha), trembling aspen (25% and 100 per ha) and white birch (21% and 500 per ha). The remaining 1% are black ash, white elm and white cedar. Approximately, there are 2500 trees per ha. It is equal to the total basal area as large as 17.4 m^2.

In the Central Part of the Swamp, white cedar (51% of basal area and 1700 per ha), white birch (21% and 400 per ha), black ash (10% and 900 per ha) and tamarack (9% and 300 per ha) are the prevailing species. There are also a lot of dead white elms (8% of area). In total there are 3370 trees per ha. The total basal area (for all species) for this area is 30.5 m^2 per ha.

The vegetation in the Northern part of the Swamp is similar to that in the South (Welch, 1978). For water balance the basal area were taken as 0.15 for North and South parts, and 0.2 for Central if water layer up to 10 cm and 0.05 and 0.1 for higher water (table 5).

I.7 CLIMATE

Background information about climate of this area is derived from summarised climatic information for Hamilton and Waterloo-Wellington climate stations (the Canadian Meteorological

Centre, Climate and Water Information Division, http://www.cmc.ec.gc.ca/climate/normals/eprowmo.htm). It is presented in table 1.

The year average of daily mean temperature is 6.6 – 7.6°C with daily extreme minimum –31.9°C in January and extremal maximum 37.4°C in July. Total precipitation ranges from 890 to 920 mm (evenly distributed during the year). 83% of total precipitation falls on rain. It is interesting that in the winter months (December – February) there is high percent of rains also – from 37 to 55. Extreme daily amount of rainfall reached 90-107 mm in July, and snowfall – 35-43 cm in December and January. Normally snow cover persists for 5 months from November to March. Snow pack depth is 16 cm on average (on the airport area), for Beverly Swamp it amounts 45 cm (the only data of 1973-76).

II. WATER BALANCE

There is no enough data for exact decision, but this balance was considered using the area-separation method and gives basic imagination about swamp hydrology.

II.1 YEARLY BALANCE

The year water balance components were considered by Valverde (1978) using data of 1968-76 as the following equation:

$$P + I - Q - E = dS, \qquad \text{(II.1.1)}$$

Where

P – year amount of precipitation on the swamp area, mm

I – total year inflow to the swamp area, mm

Q – total year outflow, mm

E – evapotranspiration from the swamp area, mm

dS – change in water storage in the swamp, mm.

Total amount of precipitation was obtained for the Beverly Swamp from Valens station from Valverde (no more sources). The rain-snow ratio was taken as equal as Hamilton-Waterloo stations have. Rain amounts to 683.8 mm, snow – 150.3 mm, their sum - 823.5 mm.

Average amount of outflow through Westover cross section is equal to 0.66 cubm/s. It is equal the water layer depth as much as 330 mm (data from Environment of Canada).

Calculated year inflow (405 mm) is bigger than outflow. It should be much bigger, because local inflow was not taking into account due to very little information about even the creek inflow. It is clear from topography and geology of Beverly Swamp. Approximate picture of local drainage is given in fig.4. This was based on water levels measurements at different outlets (fig.5). To get full inflow it is necessary to have detail microrelief and creek flow measurements.

So, approximate year water balance can be described as

$$823.5 + 405 - 330 - 898.5 = 0 \qquad \text{(II.1.2)}$$

where

898.5 mm – annual evapotranspiration from Beverly Swamp obtained from year water balance as a residual.

For long-term water balance the change in water storage and soil moisture usually is equal 0 and we use it statement also. However, for wetlands it should be some amount for annual growth of wet vegetation and peat (Ivanov, 1975). Obtained evapotranspiration should include this amount. But data pattern does not allow doing so detailed balance.

II.2 MONTHLY WATER BALANCE

For month water balance we need more detailed knowledge about hydrological processes on the Spencer Creek watershed and particularly Beverly Swamp. Very detailed but not such a full knowledge is available from the reports presenting results of an extensive monitoring program in Beverly Swamp had been provided during 1973-1976 (Woo, 1978). However, month water balance was considered as follow:

$$P - S + Sp + Ri - Ro + dG + dM = E \qquad \text{(II.2.1)}$$

Where

P	– month amount of precipitation on the Swamp area, mm
S	- water content in snows cower, mm
Sp	- water content in snow in previous month, mm
Ri and Ro	– creek inflow and outflow of the Swamp, mm
dG	- changing in swamp water storage, mm
dM	- changing of water storage in unsaturated layer, mm
E	- evapotranspiration, mm as a residual

It is necessary to say that this water balance cannot provide high exactness due to available data is very casual, from different years and sites of the swamp. The only measured component is the outflow from the swamp. The all others have different exactness and approach to average. In this case the area-separation method is very adjunct.

II.2.1 AREA SEPARATION

Usually separation of the different parts of the swamp bases on visible morphological and vegetation dispersion of each part. To estimate the sizes the topographic map was used. Obtained results are given in table 2.

As was mentioned earlier the separation of any swamp system is based on estimation of microlandscapes. In our case the north and south parts of the swamp were taken as a maple wood microlandscape with the only difference – the elevation above sea level for the north part is 10 cm higher than for the south one.

The central part was taken as cedar forest microlandscape for precipitation estimations. For groundwater table fluctuations it is more complicate due to having former lake in its Northwest area. The measure of this lake is taken as 0.7 km², because it should be between crossing the swamp boarder by Spencer Creek and the west edge of Hydro transmission, which compiles with western profile that does not indicate presence of lake. It means that lake locates closer to the swamp boarder than to the transmission.

Vegetation and underlying rocks of the central and south parts have been described and investigated more or less definitely. The North part was taken as the same as the South one due to very similar visual relation with streams. In both cases the stream just concerns an edge of the swamp's part.

To estimate local drainage areas for every part (fig.4) and watershed for tributaries it was needed to make some estimation of stream flow in the Swamp, which was done July 13 by author (table 3).

There are four parallel measurements of water discharges in the Valverde thesis that were made in summer 1975 (table 3). These data clearly shows that inflow excesses outflow in summer period. Estimations of water discharges July, 13 current year have confirmed this fact and helped to obtain lack of watershed information. Comparison between Fletcher and Spencer discharges before the swamp (0.068 and 0.006 m³/s, correspondingly) shows that watershed area of Spencer Creek should be smaller than Fletcher significantly. However, the runoff per unit area (specific runoff, module, l/s km²) should be approximately the same as for Main outlet in the middle of the swamp (due to very similar conditions – reservoir upstream). Numerical expressions of them are given in table 4.

Such a detail separation of Beverly Swamp was not used in this water balance, but it might be very useful for further estimations and assessments.

II.2.2 PRECIPITATIONS

Precipitation on Spencer watershed is measured on Beverly Swamp (Tower site) from1985, in Valens from 1968 to 1986 (Roncato-Spencer, 1991), in Millgrove for downstream watershed (Valverde, 1978). For water balance the Valens month's precipitation was used. Beverly precipitation was used only for analysis and obtaining the spatial and temporal distribution of precipitation within the swamp. Correlation between snows and rains was taken from Hamilton and Waterloo climate stations (table 1).

Monitoring program for Hydro transmission from fall 1973 till end 1976 had observations on precipitation also. First two years there were snow observations only. During winter 1973-74 they were on the one open site near the tower 9 (tw.9). There were four sites next winter: open site near tw. 9, forest sites were near the tw. 13 and southern of it, and the third forest one was near confluence of Spencer and Fletcher Creeks. Since the summer 1975 rain observations had been started at three sites that referred to as tw.13 site, Control site (southern of tw. 13) and South test site (tw. 8). Open site that summer was equipped by a recording rain gauge (Woo, 1977).
Open site located on the mineral soil between South and Central parts of the swamp. Tower 13 and Control or southern of tw. 13 sites were on the right bank of Spencer Creek after its reappearing from the swamp. Confluence site was in the very middle of Central part of the swamp. South test site was near quarrel and tw.8.

All measurements have been done weekly excluding the Open site equipped by gauge.
All sites included several points of measurement. Snow cover and snowfall were measured separately.

Total amount of precipitation in open area of the swamp just the same as in Valens, Guelph or Millgrove (Valverde, 1978) that indicate precipitation on the whole Spencer Creek watershed. Difference originates from interception by three canopies. As was shown the maple forest that is prevailing in the South and North Parts of the swamp less effective than the cedar one, which covers the Central part of the swamp. In summer period the interception in the maple forest can be as 12 – 16 % as well. For the cedar forest it can be estimated using formula from Woo (1977):

$$Po = 4.7 + 1.24\ Pf \qquad \text{(II.2.2.1)}$$

where
Po and Pf are precipitation on open and forest areas. In 1975 amount of the intercepted precipitation in the cedar forest during warm period was equal to 32% (fig.6).

Cold period has another picture with distribution of precipitation. Openings such as Hydro transmission is big enough for snow drifting. A forest collects more snow (~ 10%) due to less wind and more shadow and its snow stays for two-three weeks longer than in the openings (Woo, 1976 reports, Valverde, 1978). Actually, forest doesn't. Simply ground area in forest is less than open one due to trees, so snow depth is higher. And it is true that forest keeps snow for longer time due to shadow. It is very good seen in the fig. 7 – 9. Snow conditions in forest are 40 mm in late April, snow in open area has 15-20 as a new formation (after melting). Relative water equivalent in the forest changes slower than in open area. In the beginning of winter snow pack in forest melts easier than in open area (fig.10). After frizzing the soil the forest snow pack grows easier. The new snow has much less water than old one. The temperature of the ground surface fluctuates very close to 0 (fig.11), so the old snow has always higher water equivalent than the new one (fig. 8, 9). In the open area the old snow contents more water than snow in forest in cold winter and vice versa in warm winter.

The water content in snow was obtained from the reports for Hydro (Woo, 1977), and in the balance amount of precipitation reaching the ground surface was considered relatively simply:

$$Pgi = Pi - Ii - Si + Si\text{-}1 \qquad (II.2.2.2)$$

Pgi – precipitation reached the ground in an examined month
Pi – total precipitation in the same month
Ii – interception in the same month
Si – water content in snow in the month (some average amount from the observed data, Woo, reports to Hydro, 1977)
Si-1 - melted snow (water content in snow from the previous month)

Average amount was obtained with taking into account the shares of each part of the swamp. Finally, precipitation on the Beverly Swamp is as on the figure 12. Actually, interception has sense as a part of spatial distribution of precipitation in the swamp and is not taken into account in balance because this part is evaporated or transpirated and finally presents in the residual.

II.2.3 WATER TABLE

The measurements of water table were made in summer 1975 in three sites of the swamp: Tower 13, Control site (very close to Tower 13) and at the South site (between tower 9 and 8). Unfortunately, it is obvious that it is not enough for month balance. Independent measurements made at the same time in the same "hole" (Central Part) and between tw.8 and 9 (South part) by the Vegetation Survey (Welch, 1978) show very different water table fluctuations in Central and South parts of the Swamp that is not obvious from the fig.13 and 14. According to Welch, the level of the "western hole" does not drop more than 20 cm under the surface. There is the similar information in Munro article (1981). The other sites (also Crook, 1999) show depth more than 60 cm.

The specific yield of peat for different parts of the swamp were taken from Crook (1999) and for flood table according to Welch (table 5).

Total year changing in water storage is equal to 0 (actually –4.3 mm).

The underground amplitude of water table was taken for the north, south and the most of Central part as big as 65 cm and for the central 'hole' it is 20 cm.

The aboveground altitudes were taken as 15 cm and 30 cm, consequently. Last mark is clearly shown on the trees of central part from Concession 8 to the Tower Site (it was noticed during the trip July 13 1999).

Duration of "flood" period is taken from Westover hydrograph statistics. It begins on 55th day from the beginning of year and ends on 128th day.

II.2.4 WATER STORAGE IN UNSATURATED LAYER

This part was considered using results by Munro (1984). Unfortunately, there is no exact notice about places of sampling and water table measurements making during three years (1976, 77 and 78). The only information is: "… from a central location within the Beverly Swamp …" (Munro, 1984). We have known that the Central part of Beverly Swamp is not homogeneitive and the place of observation is very important in result interpretation.

Month changing in water storage of the unsaturated layer was estimated as changing in moisture deficit depending on water table fluctuation:

$$dM = dSd = f(Z') \qquad (II.2.4.1)$$

Where
dM - changing of water content in unsaturated layer for i-month, mm
dSd - changing of water moisture deficit in unsaturated layer for I-month, mm
f(Z') - function of distance from the surface to the water table in m. This function was taking from Munro (1984) as some average of three year result (fig. 15 and table 6).
This ratio was taken for whole swamp due to absence another data. But every part was considered separately according to its water table position in each month and then summarised for whole swamp according to the area share.

II.2.5 INFLOW

There is not very much real information to estimate this component. All real information is in table 3 (fig.16) and table 4. We have known that inflow comes via Fletcher Creek (37 km²) and Spencer Creek (8.3 km²). Then the peat massive has water income through its boarder line from its local watershed (3 + 1.2 + 4.5 = 8.7 km²). Difference between watersheds of inflow and outflow amounts 8.4 km² (swamp area) that is 13% of outflow watershed. Actually, this information was not used for inflow estimation. Maybe it will be useful for future assessments.
For inflow estimation the following assumptions were taken:
Correlation between measured (table 3) and month average discharges at Westover (fig.17) is approximately the same as for the other outlets (inflow outlets). It is for period from May to October.
Correlation between the inflow and outflow specific runoff (the runoff per unit area, l/s km²) for cold period is taken as 1.1 for November and December and 1.0 for January – April.
There is month inflow-outflow ratio (Mi/Mo) for specific runoff in fig. 18.
Total amount of inflow to the swamp is equal to 405 mm per year.

II.2.6 OUTFLOW

The outflow from the swamp for long-term (1971-97) is equal to 330 mm (Environment of Canada). It is the only completely observed data in this estimation. Fig. 17 represents the month hydrograph of Spencer Creek at Westover outlet.

II.2.7 EVAPOTRANSPIRATION

Evapotranspiration was obtained as a residual component of water balance (table 7 and fig.19). It is normal for throughflow peat lands to have evaporation approaching to its possible upper limit (potential evapotranspiration) and excess even precipitation (Ivanov, 1975, Bogoslovsky and all, 1984). That is why they could not be as regulators of runoff – they simply spend collected floodwater for evapotranspiration.

For comparison there is only data were experimentally obtained by S. Munro (1984). His result was 4 mm per day from down to dust for July and August (120 mm / month). It is also very big numerous, but it is very close to summer balance residual. For using this data we need to have information about condensation in dark period of day.

Comparing with evaporation from Estonia (Vedom, 1996) – 400-450 mm – 900 mm for Beverly Swamp is very reliable numerous, because it is very small specific area with more precipitation (700 mm in Estonia), less humidity (93% is average humidity in Estonia) and higher air temperature (12?C the average air temperature of warm period in Estonia).

Obtained water balance of cause has very approximate character. But it 'is the critical factor as flooded soils provide the anaerobic conditions necessary for the methane producing soil bacteria. However much of this production can be oxidised in the upper aerobic layers, which is under water table control' (Beran, 1995). It is the model, which can give not only average information, but routine also.

It gives the initial information for swamp 'water usable storage – outflow' model also.

III. 'WATER USABLE STORAGE - OUTFLOW' MODEL

Water balance of the Beverly Swamp (Vedom, 1999), geological profiles (Valverde, 1978) and the method of lake usable storage coefficient (Vedom, 1995) are the initial points of this estimation.

The method of lake usable storage coefficient (the lake method) was developed as a lake application for water resources estimation and for the first time it was exploited for the swamp. The main factor that pursuit to try this lake method for the swamp is the swamp's geological situation. Beverly Swamp locates in the depressions like a lake in its bowl. The only difference between lake and this particular swamp is the filling of these depressions not only water, but a peat and a friable ground inside. Besides, some part of the swamp was as lake long time ago (western 'hole' in the central part).

Some words about the method of Lake usable storage coefficient.

III.1 THE METHOD OF LAKE USABLE STORAGE COEFFICIENT

The main idea of method is:

Lake adjustment capacity is measured by usable storage coefficient (b), which indicates changing of water storage not only in lake but also in whole drainage basin and depends on climate and geology conditions.

The lake usable storage coefficient b is equal

$$b = W/Wo = \frac{Ao^* K^* 1000}{(1+K)^*Mo^* To} \qquad \text{(III.1.1)}$$

Where

W - lake usable storage, m^3

Wo - lake outflow, m^3

Ao - year or month average water level amplitude for the examined period, m

Mo - year or month average specific outflow (the outflow per unit area of its watershed) from the examined lake, l/s?km². (To find flow in m^3/s it is necessary to multiply M by watershed area in km^2 and divide by 1000).

To - duration slice of the calculated characteristics in seconds (for the year To = 31.54 mln. sec., for the month To = 2.68, 2.59 and 2.54 mln. sec. according to 31, 30 or 29 days (2.63 as average)

K - year or month average lake area index

K = Fl/(Fw – Fl) (III.1.2)

Fl - lake area according to the year or month average water level, km^2

Fw - lake watershed area, km^2

Shortly, the method can be described as following:
Creating of the b = f (K) ratio for the lakes of examined region or single lake
Recalculation of this ratio into the M = f (A, K) nomogram, which indicates the correlation between outflow from lake (specific runoff, module, M), its water level amplitude (A) and lake area index. (K).
Obtained nomograms are used to estimate specific runoff for unknown lake outflow using lake area index (K), which is the very easy estimated parameter, and lake level amplitude (A).
In our case the outflow from swamp is measured. The water table amplitude is known also. Flooded areas within the swamp and M = (A,K) month ratio itself that is the main interest this model.

III.2 USABLE STORAGE OF BEVERLY SWAMP

The usable storage for Beverly Swamp actually is the depression usable storage. For its estimation the geological profiles were used again as the following.
'Hypsographs' of the depressions were based on the assumption that the slopes of depressions approximately the same all along their perimeter.
273.9 m a.s.l. was taken as a surface elevation in the balance model. Some words about elevation. This figure should obviously refer to feet, but Valverde gave it like meter, and all real sizes of deposits in the profiles refer obviously to meters. I accept this figure as meter scale.
The area of the each swamp part was referred to this elevation.
The area share of each deposit was accepted as line share from each profile and then averaged (table 8).
The north part of the swamp was actually made up from eastern profile of the south part.
The volume of each deposit in the depressions was obtained on the base of areas. In this case elevation indicates upper boarder of the volume's 'container' (table 9).
The last three items were made for upper 2m layer over every 10 cm due to better convenience.
The result of these estimations is presented in fig.20-22. To get water content of these deposits it is necessary to multiply their volume by specific yield.
The specific yield of sandy silts and silty sands was taken as 0.018, sand – 0.022, clay and marl – 0 (Vedom, 1996), peat – according to Crook, dense of forest – according to Welch (table 5).
The water content of deposits in Beverly Swamp (fig.23) was also obtained only for upper layer (table 10).

The next step in the water usable storage estimation is obtaining of real water table elevations, which regards to the balance conditions. The best way, of cause, would be the measurements of flooded water levels or the flood marks on the trees, which are quite clear at least in the central part. In our situation we can use the only possibility. It is the obtained curves of water content and deposit content.

The water table elevations for 'flooded months' were obtained according to volume of flooded water from column 'Air' in table 9 for each part. Elevations for 'dry' months were obtained using the balance water table. For the whole swamp the elevation of each part was summarised according to area share (0.355 for the north, 0.337 for central and 0.308 for south).

Thus, we have monthly elevations (fig.24) and can obtain usable storage and flooded areas (table 11, fig. 25, 26). The lake area index K for each month were obtained using equation III.1.2., where Fl is flooded area and Fw is the watershed area of Spencer Creek in Westover outlet.

III. 3 WATER STORAGE – OUTFLOW MODEL

Usable storage coefficient b was estimated for every month using formula III.1.1. Using obtained 12 corresponding meanings of A, K and b and exploiting previous information about the lake method the initial nomogram of b = f(A,K) was created (fig.27).

This nomogram was converted into two final nomograms, which can be used as routine graphs for estimation an any of three parameters – month amplitude of water table (A), outflow from the swamp (M) and flood area index (K) or water table elevation (fig.28 and 29).

These two nomograms describe water regime of Beverly Swamp in very main lines. First one gives imagination about correlation between water table changing, flooded area and outflow from the swamp in period of filling (spring, fall – altitudes are positive). Second one – in period of emptiness. That is it.

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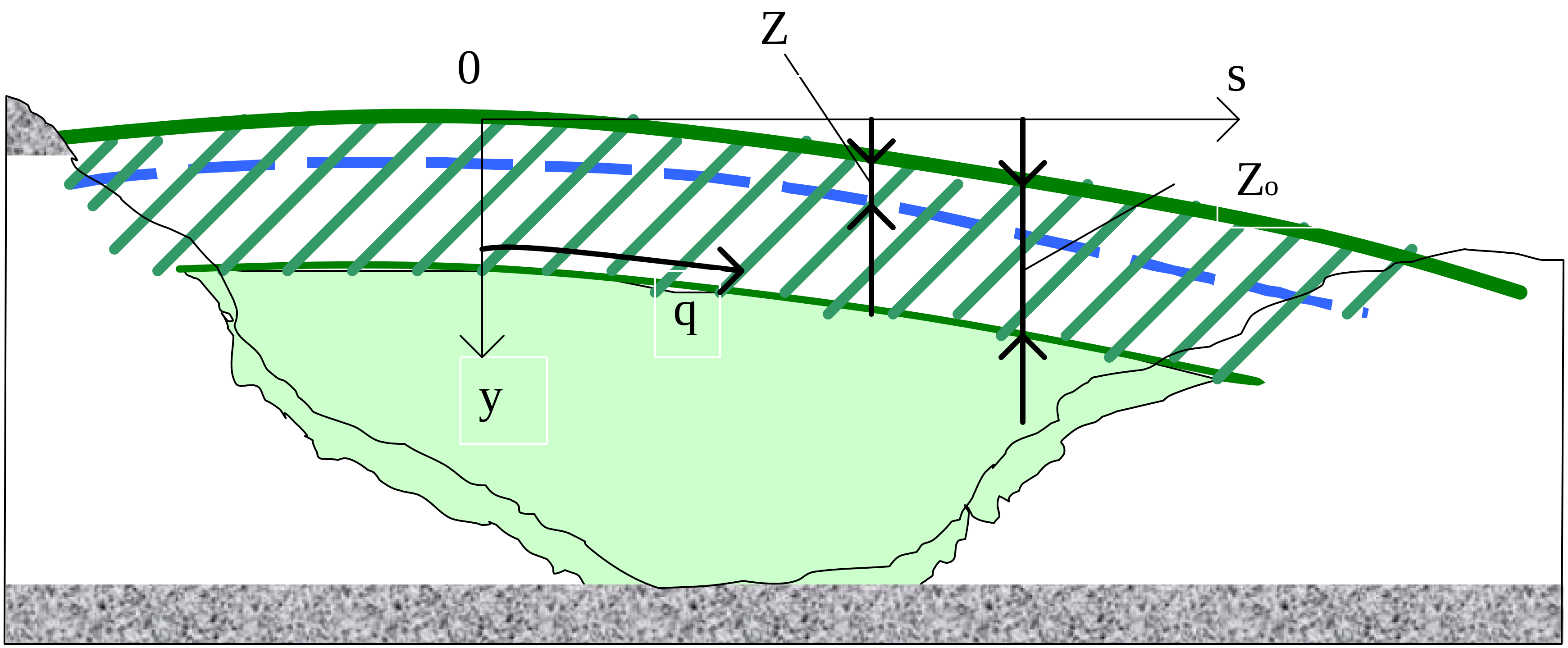
$i = dy/ds$



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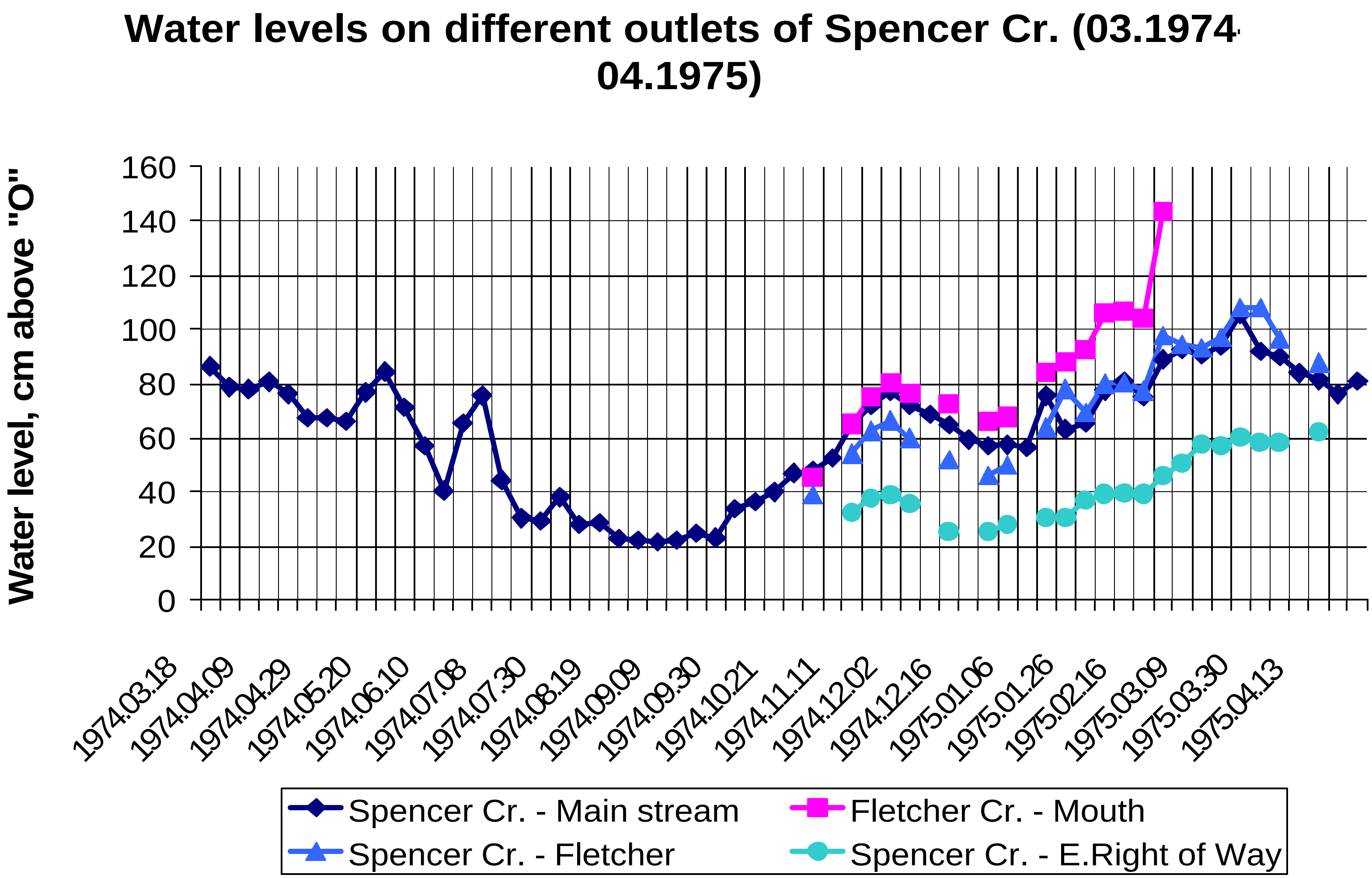

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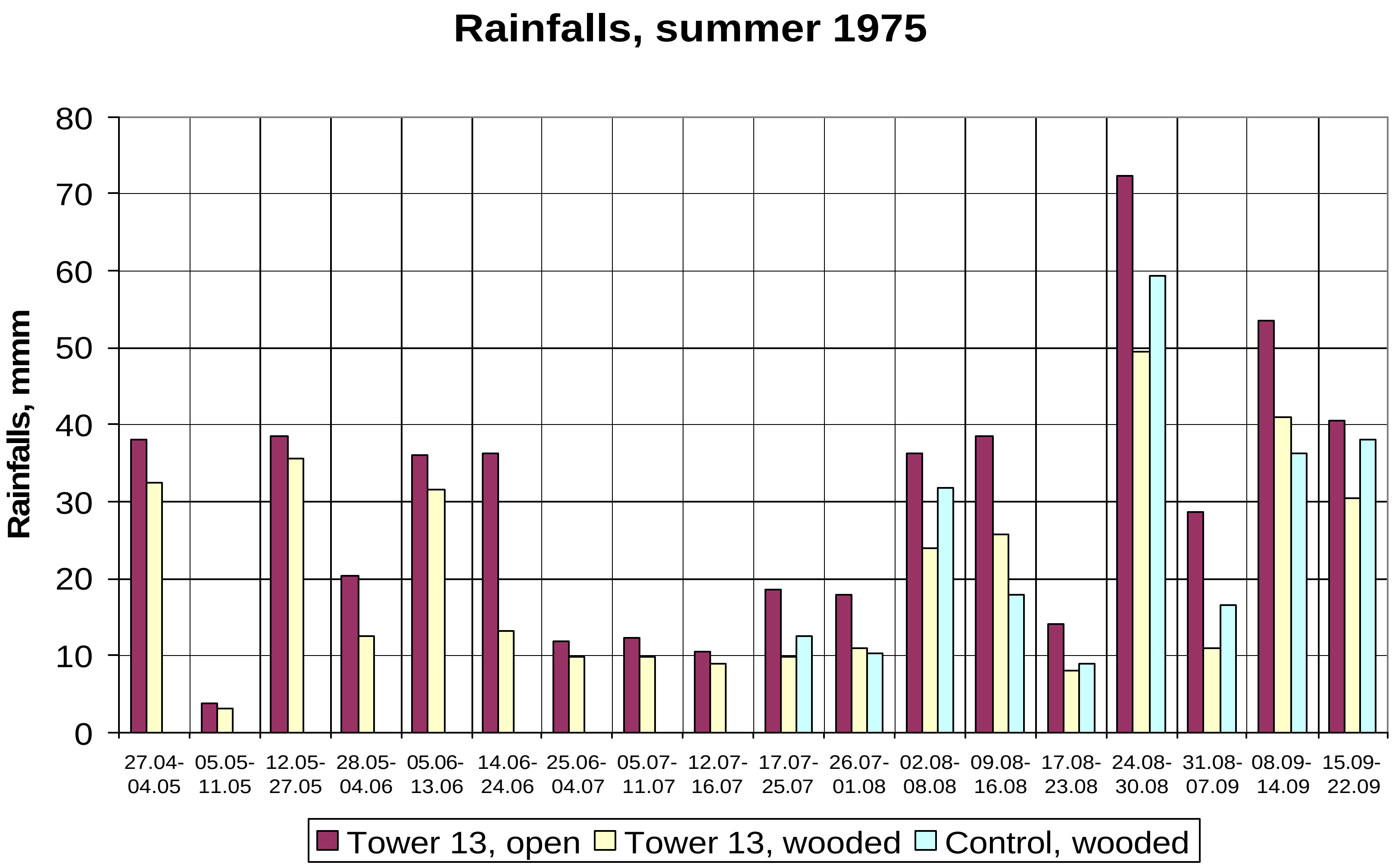

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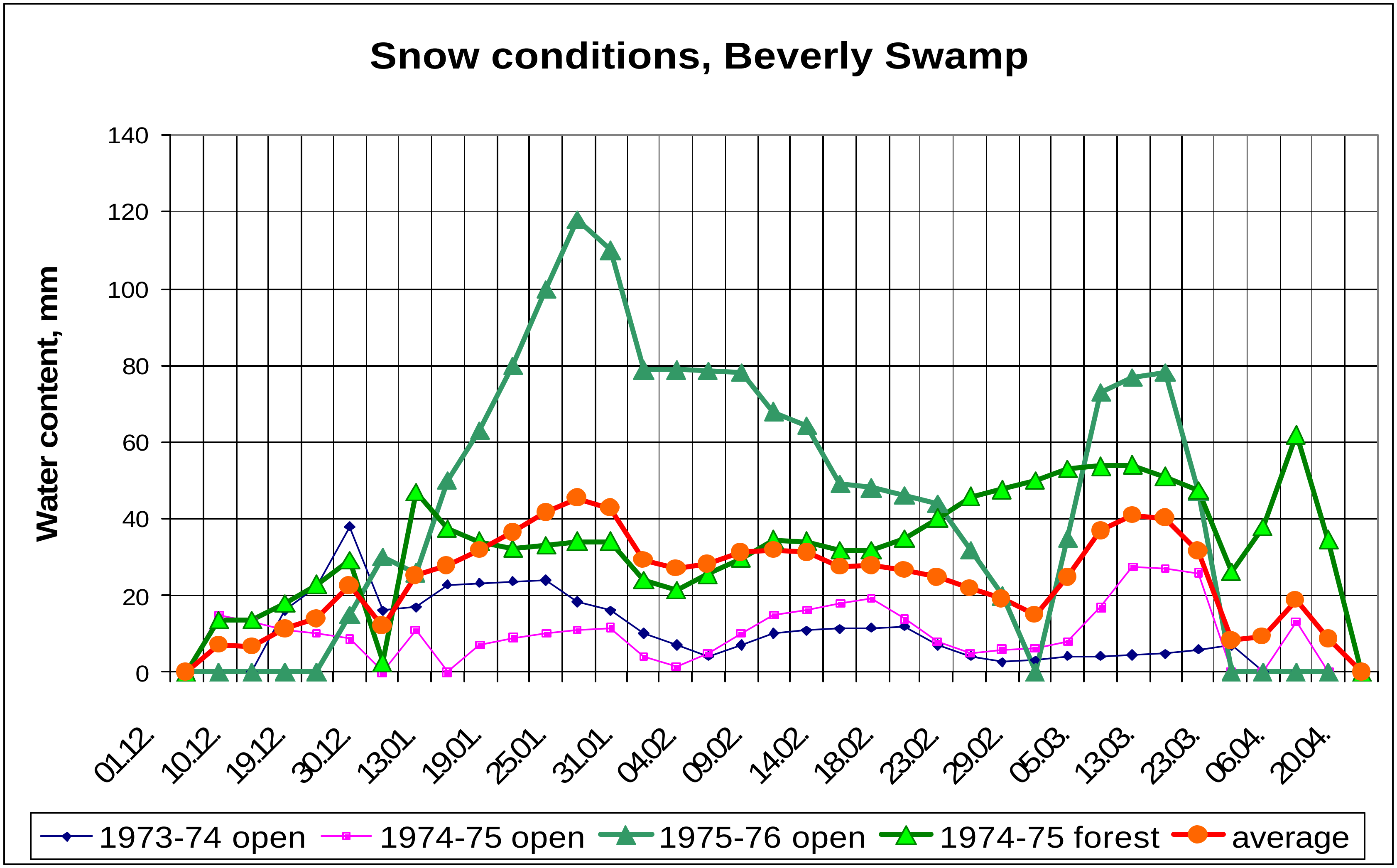

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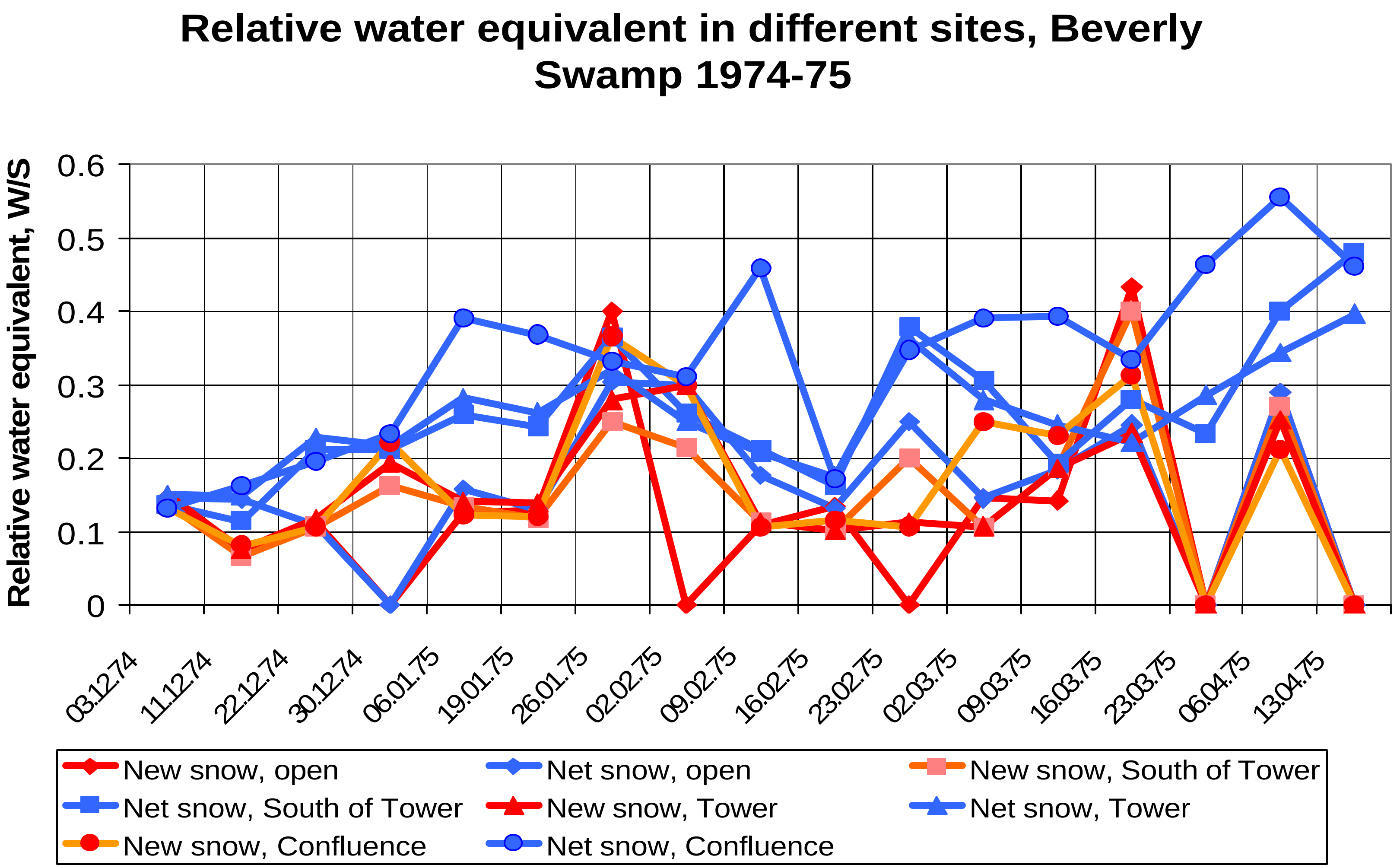
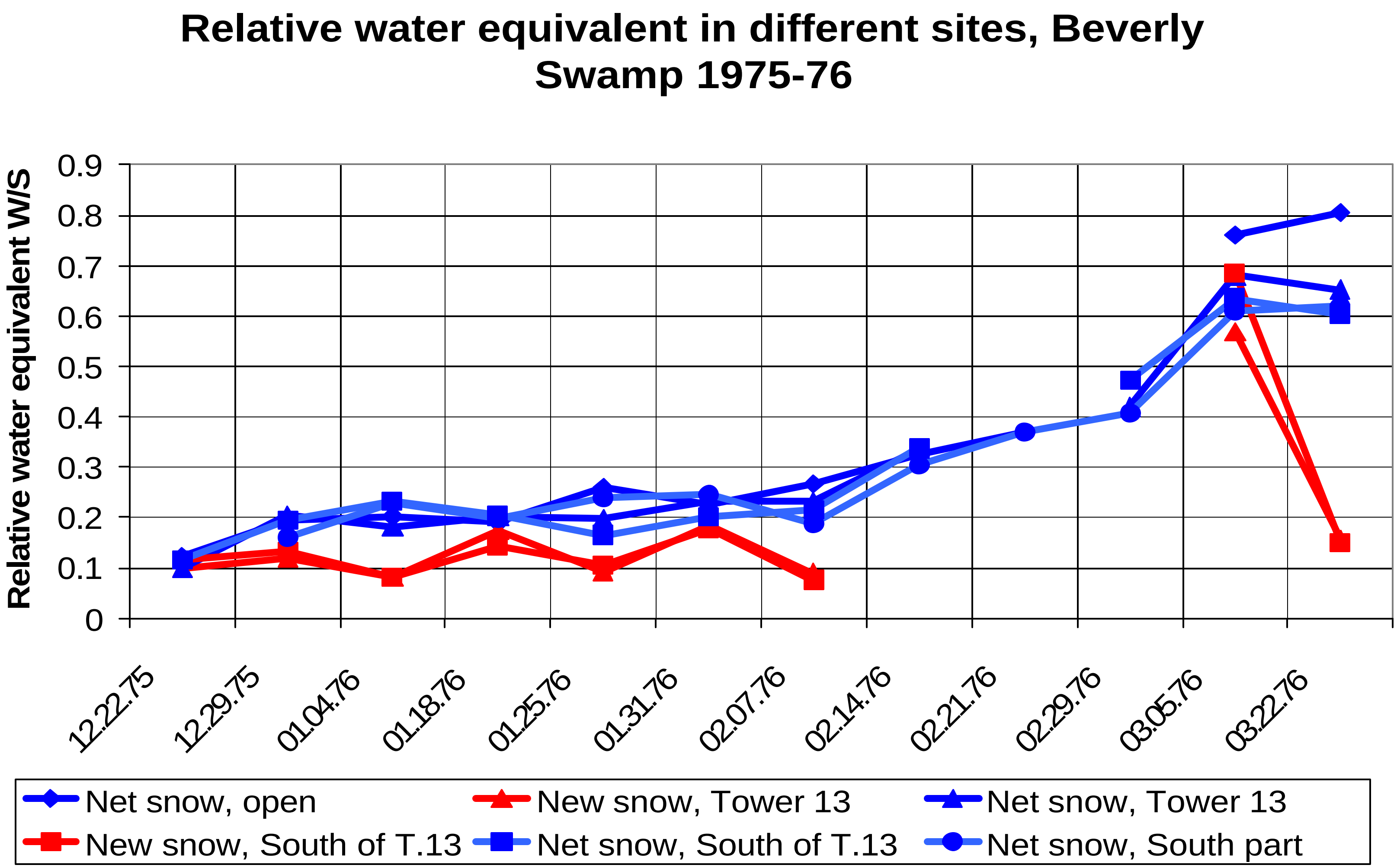


Fig. 8. Relative water equivalent in different sites of Beverly Swamp, winter 1974-75



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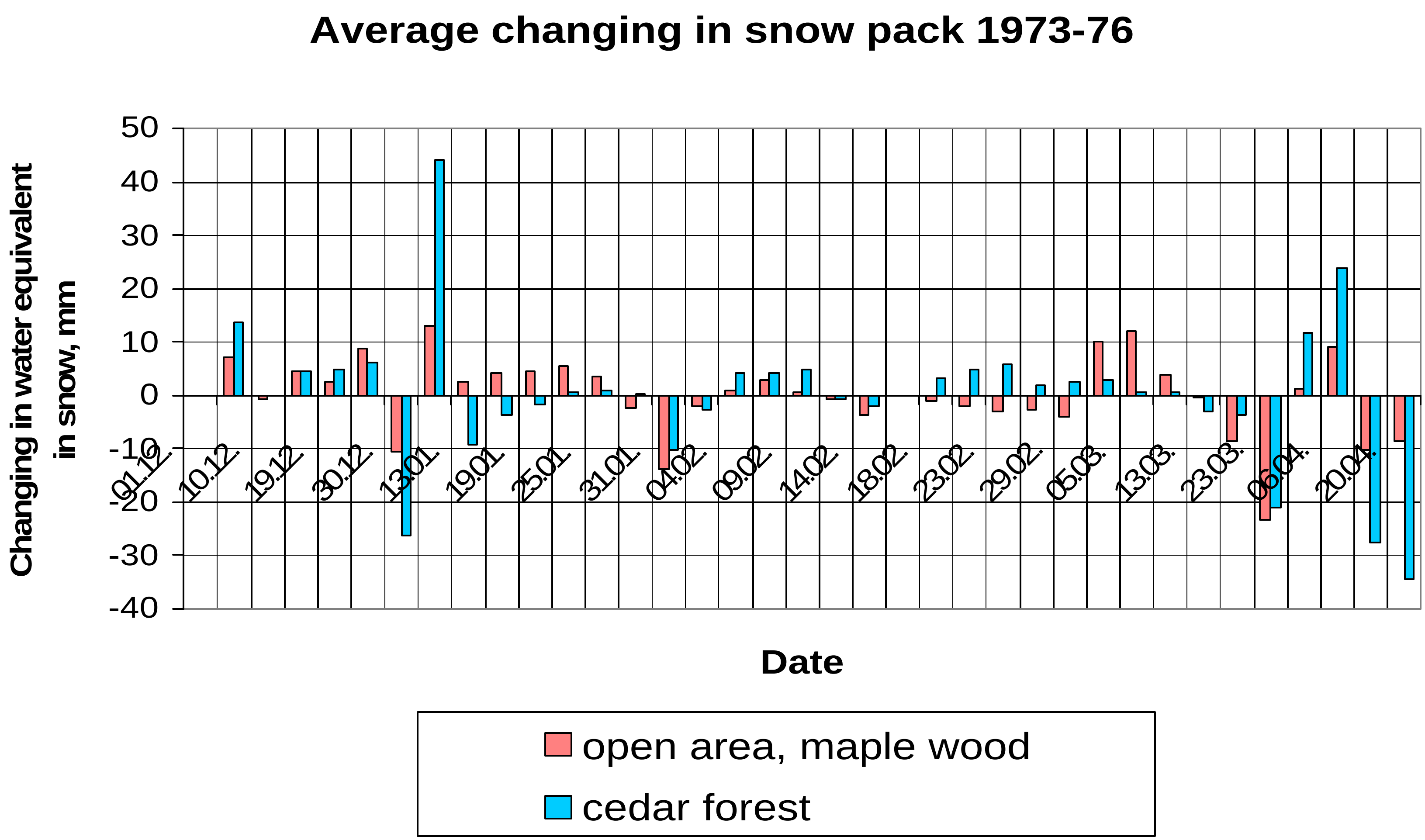

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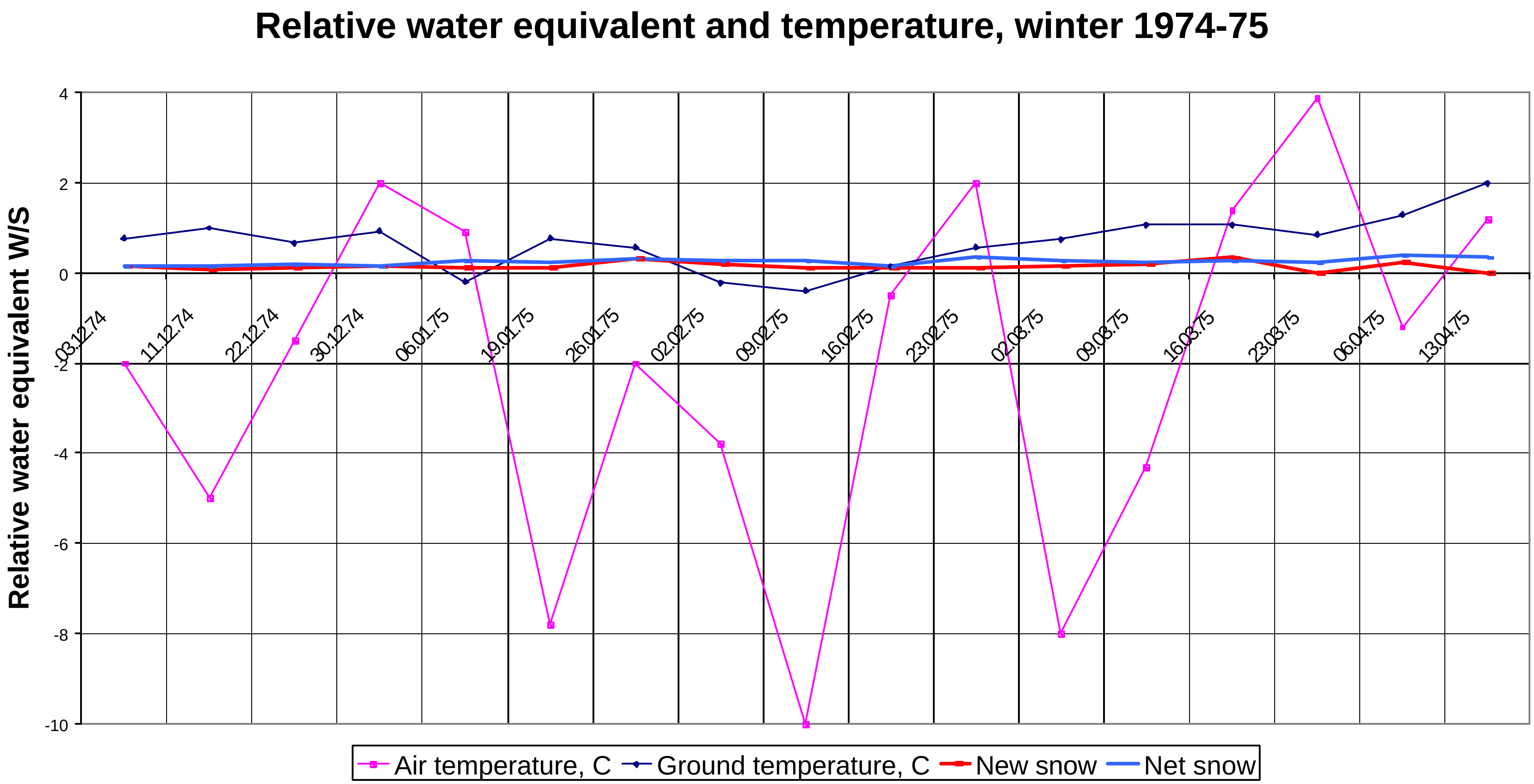

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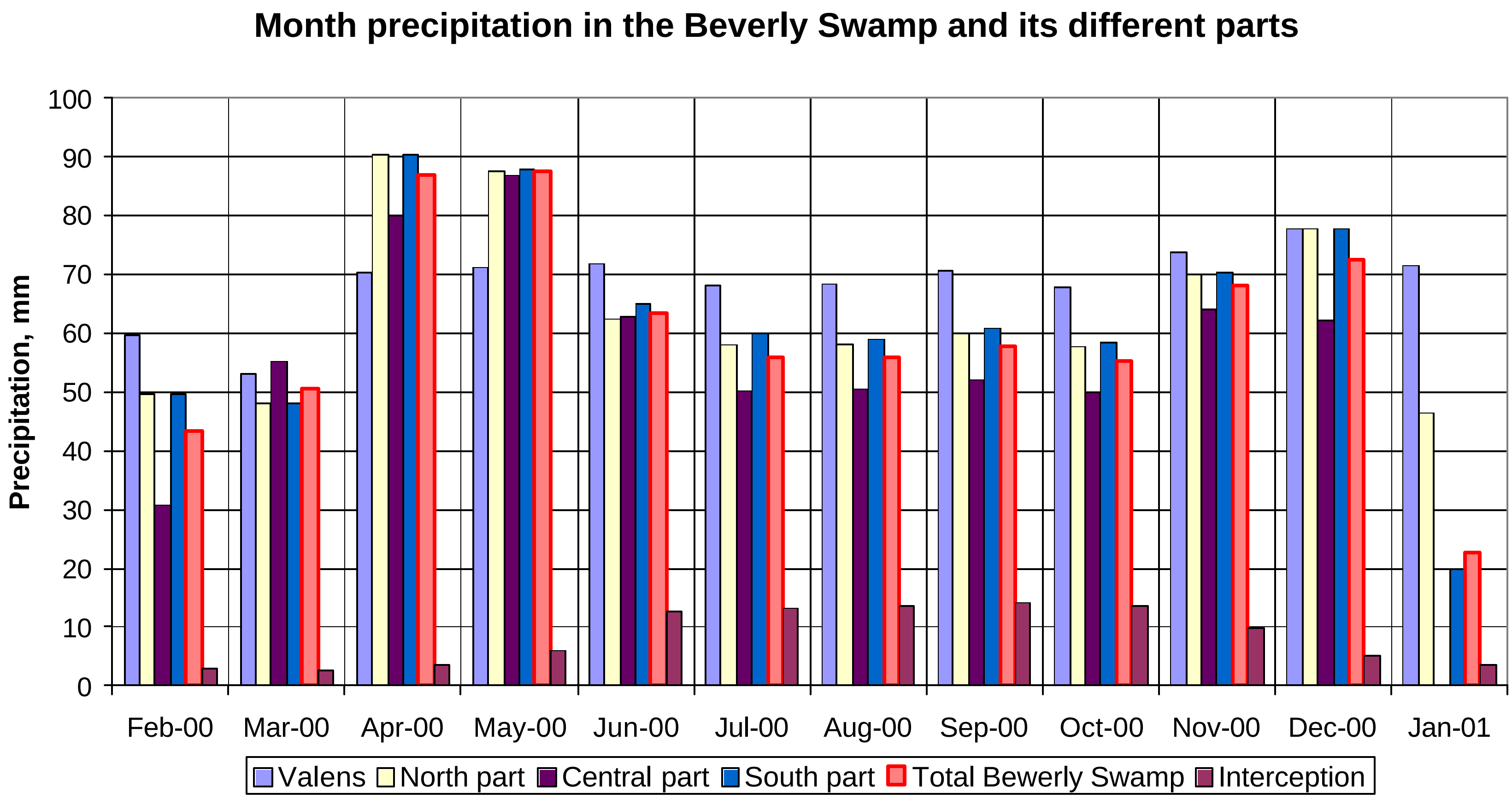

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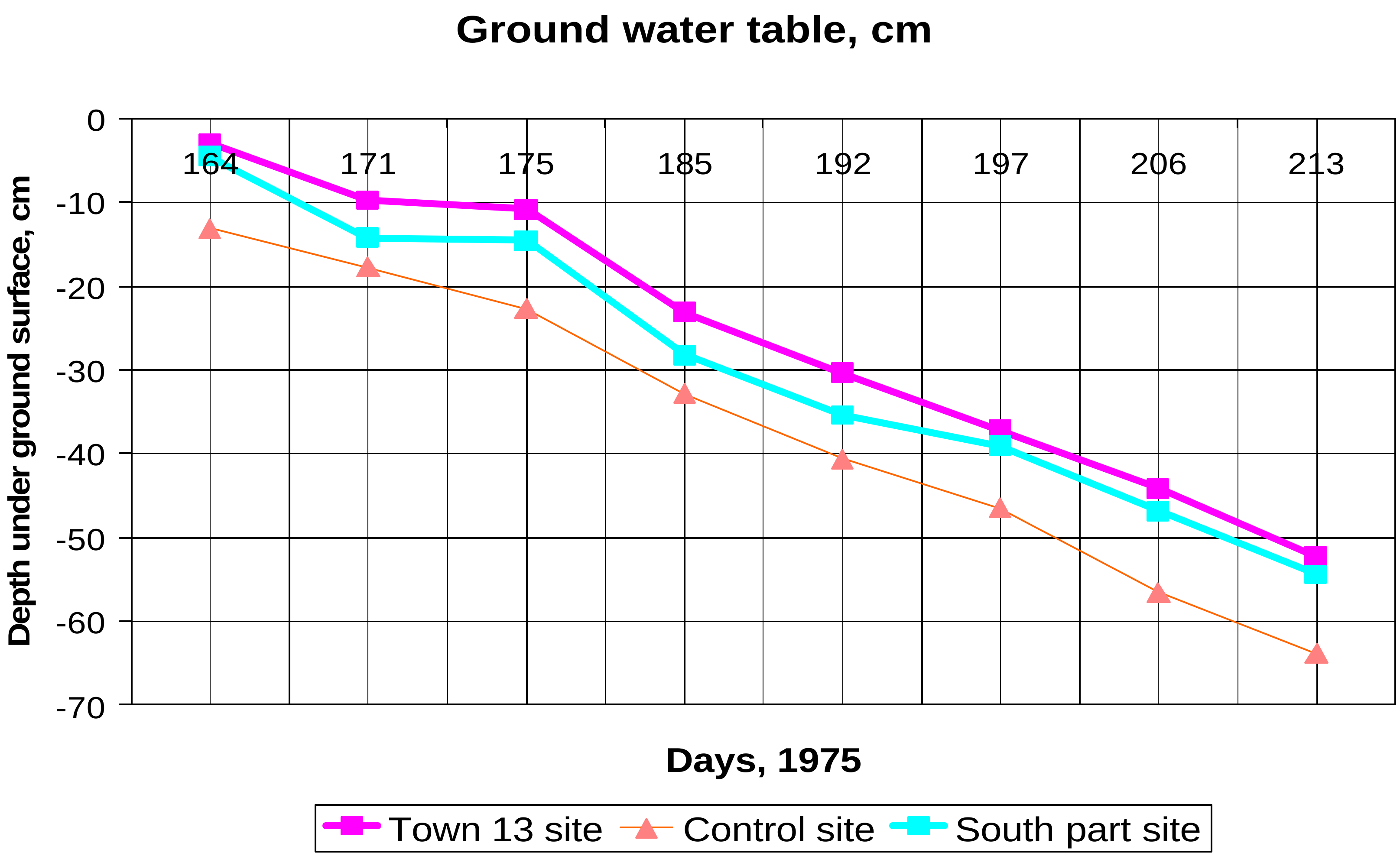

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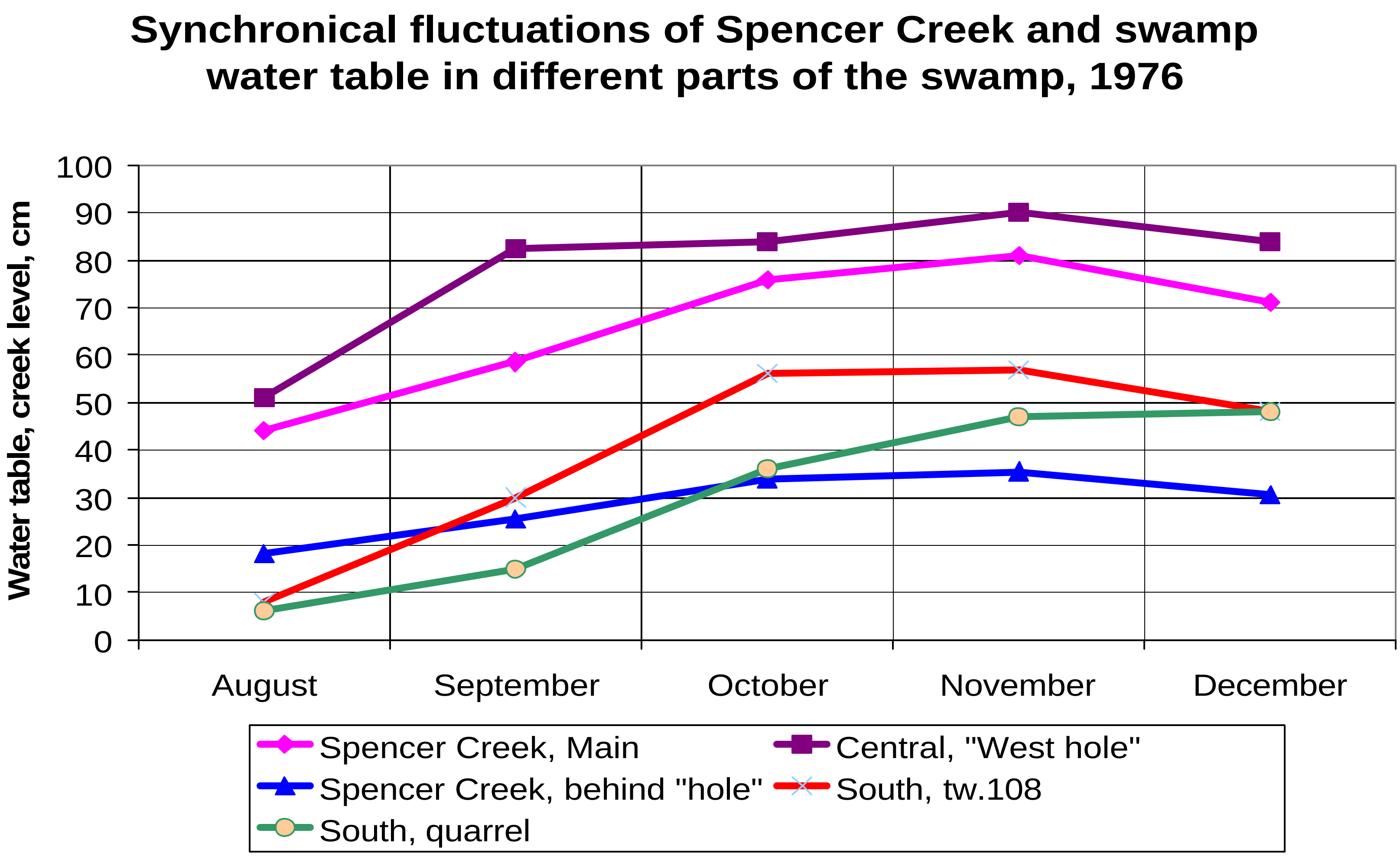

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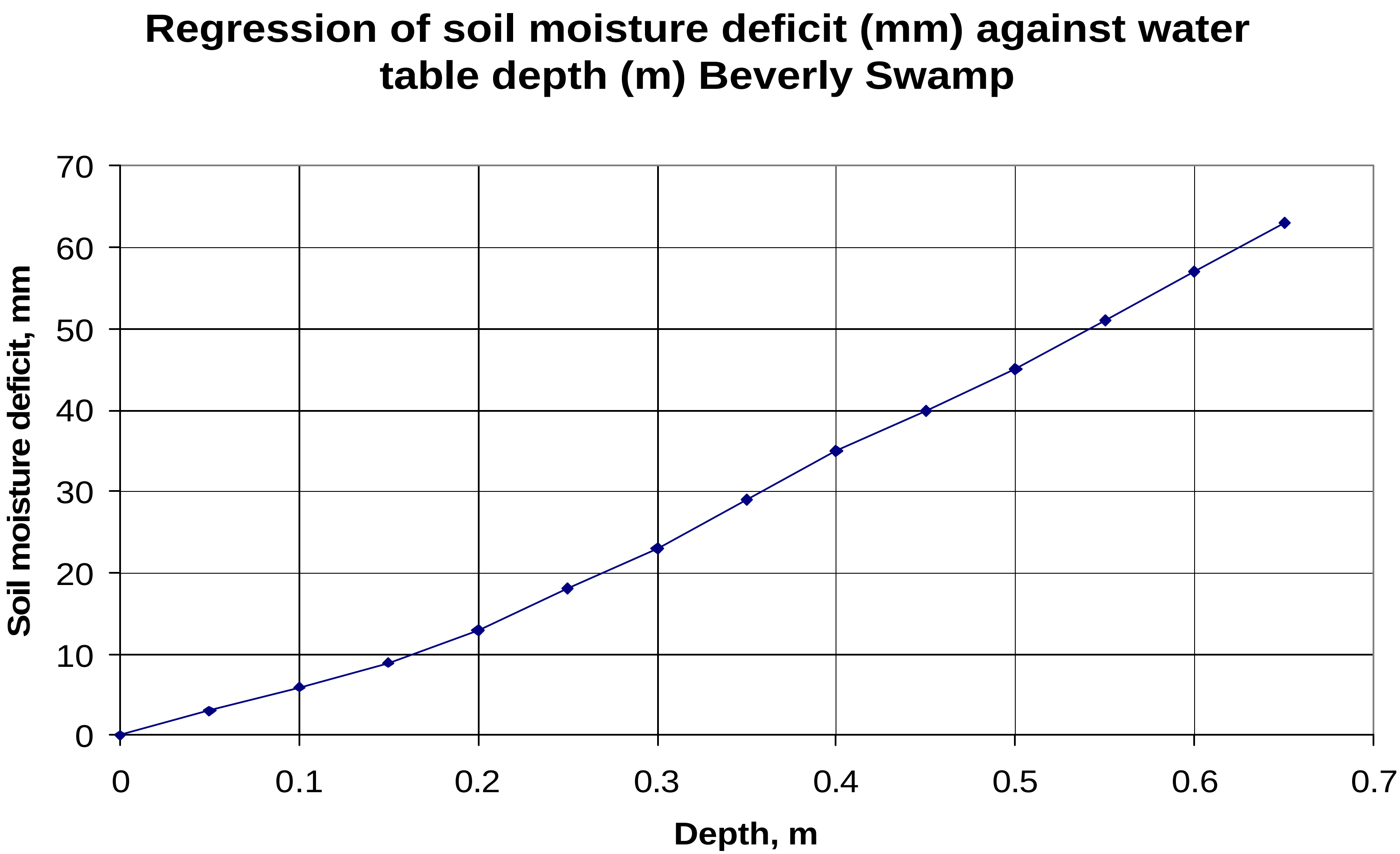

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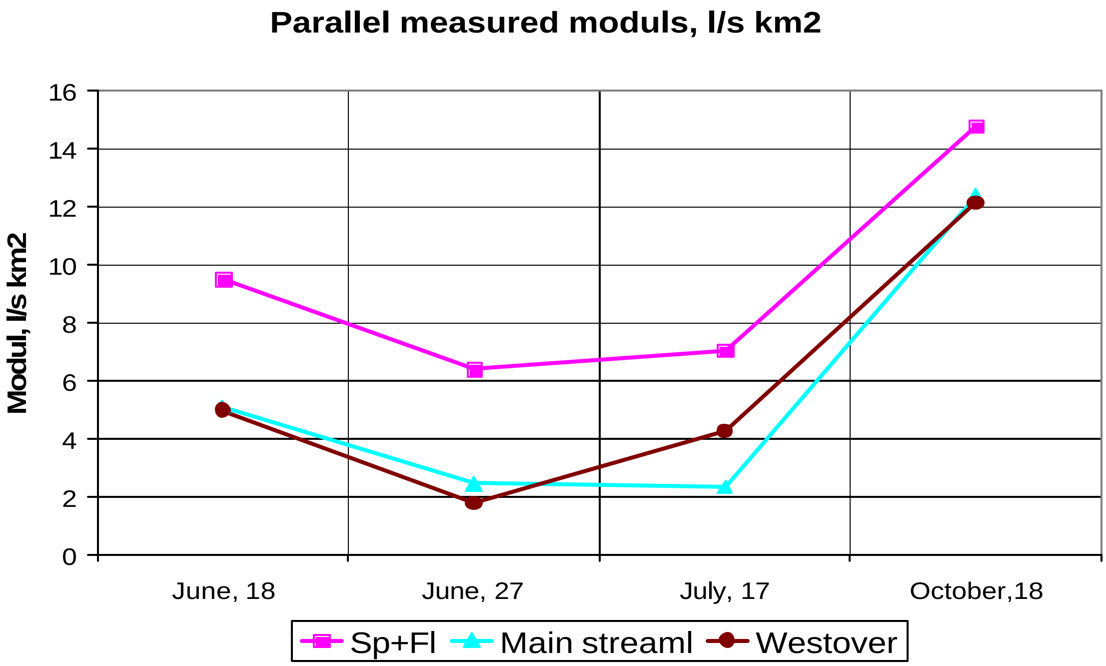

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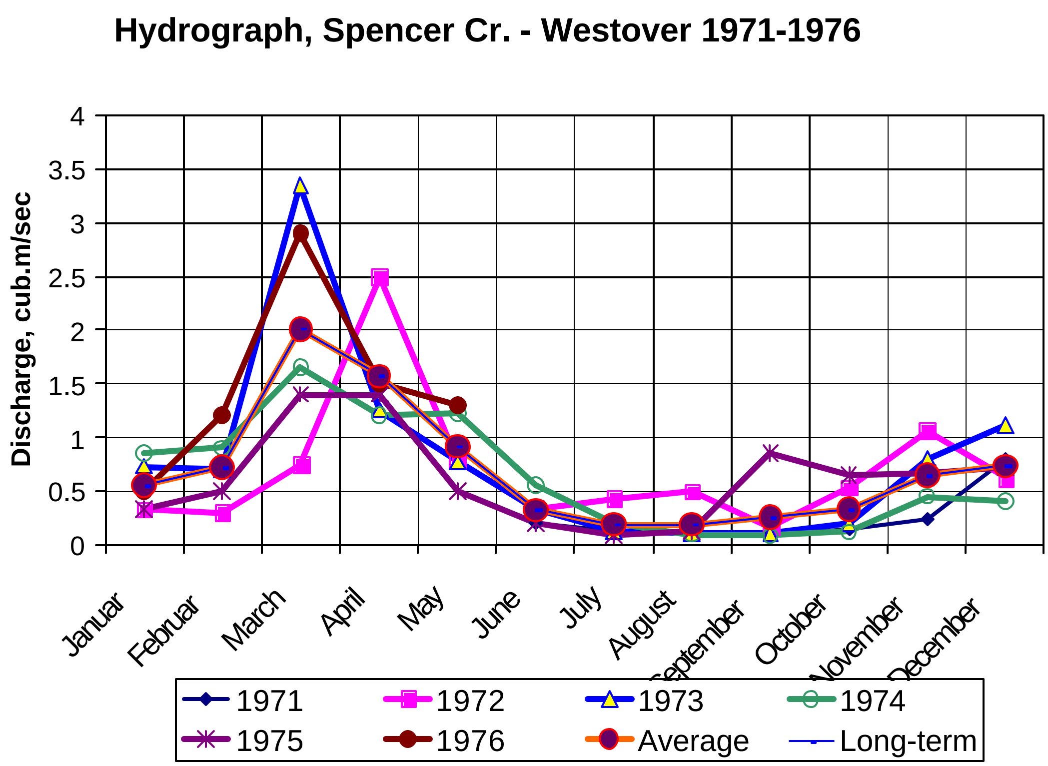

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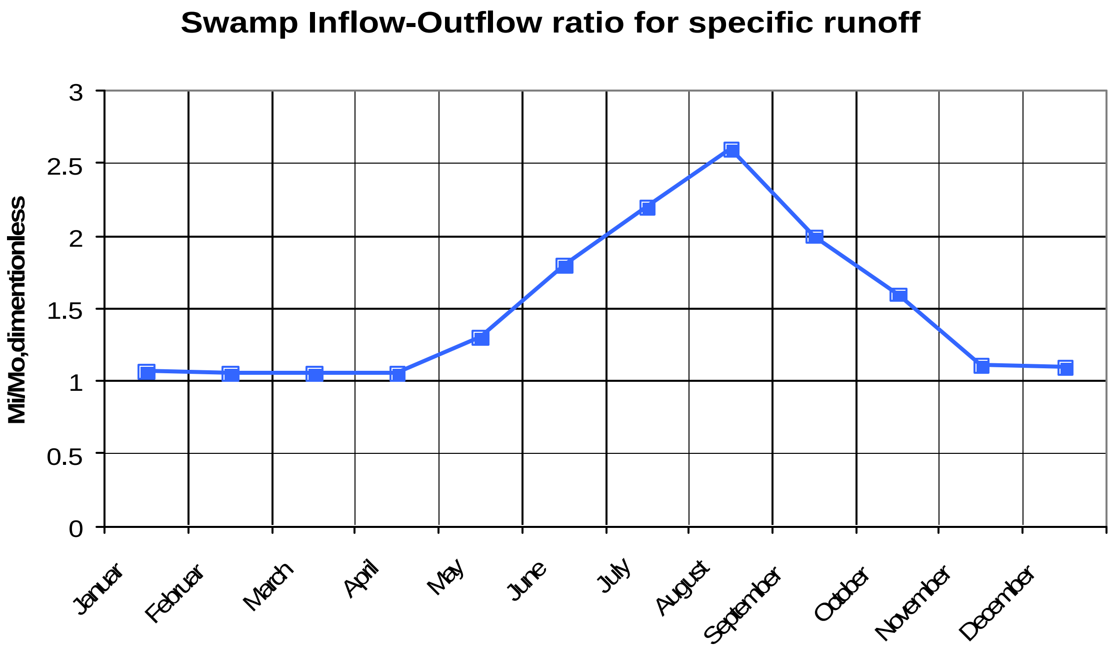

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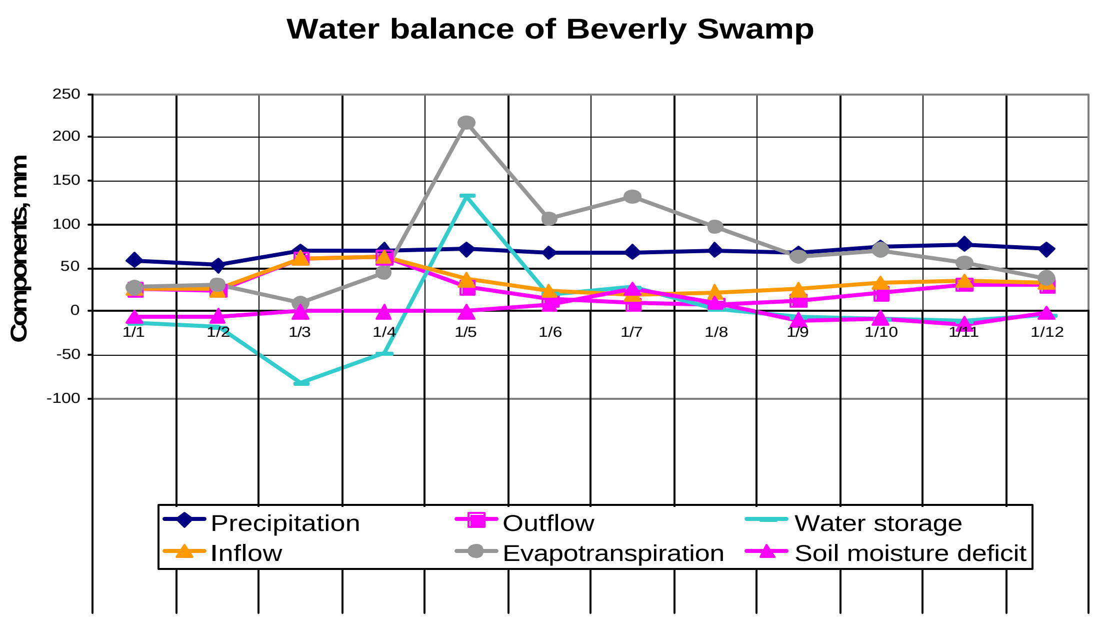

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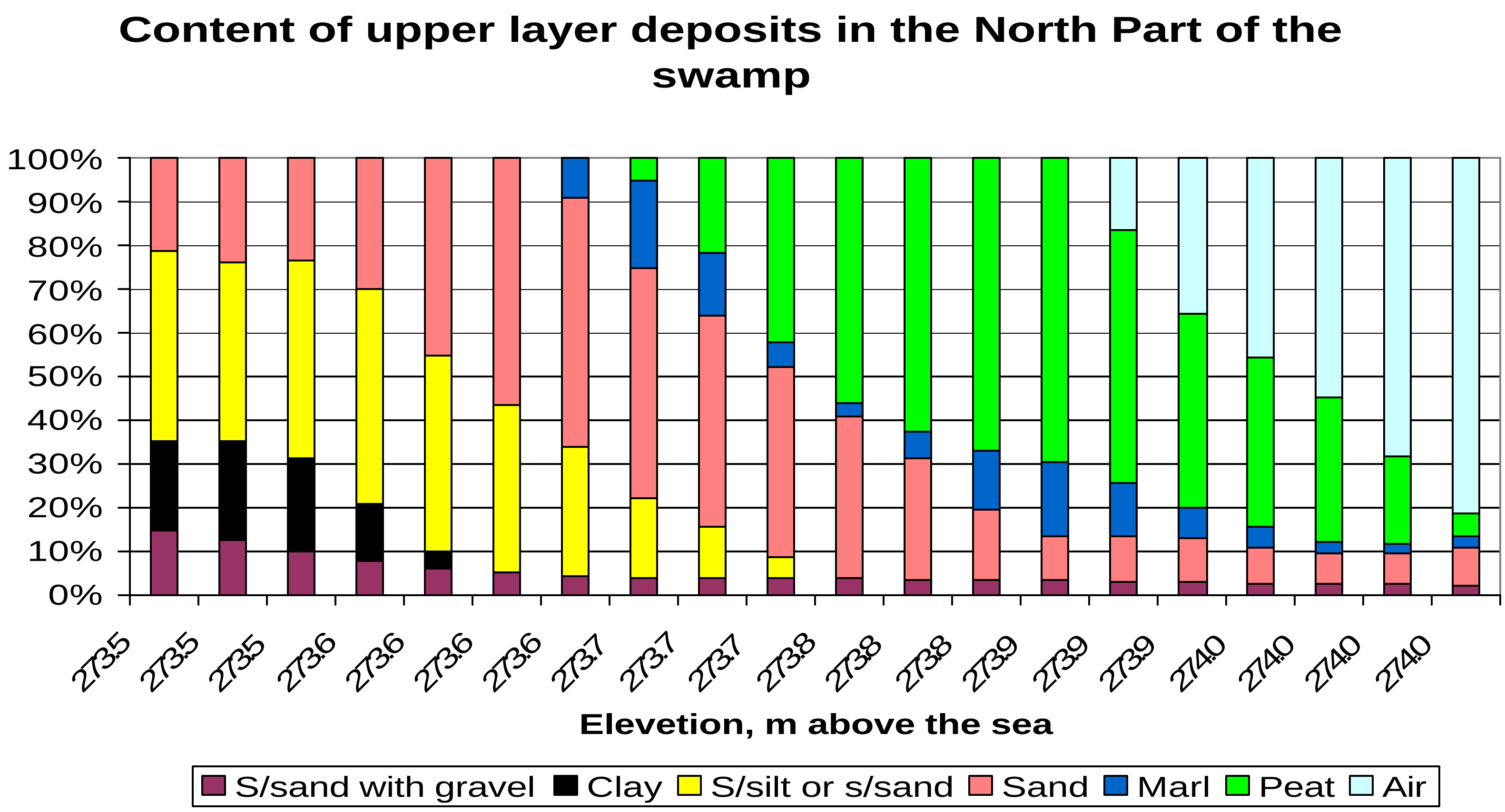

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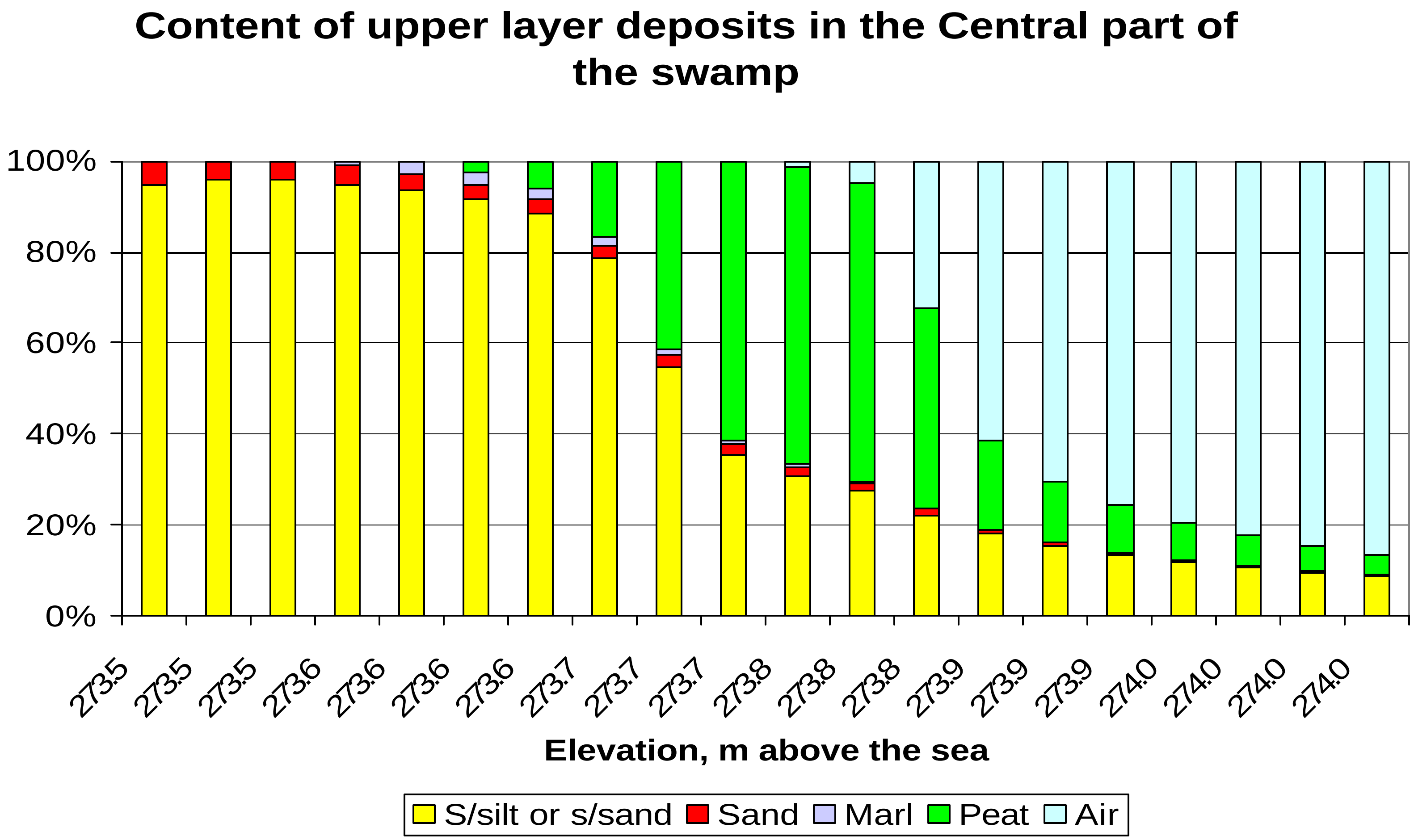

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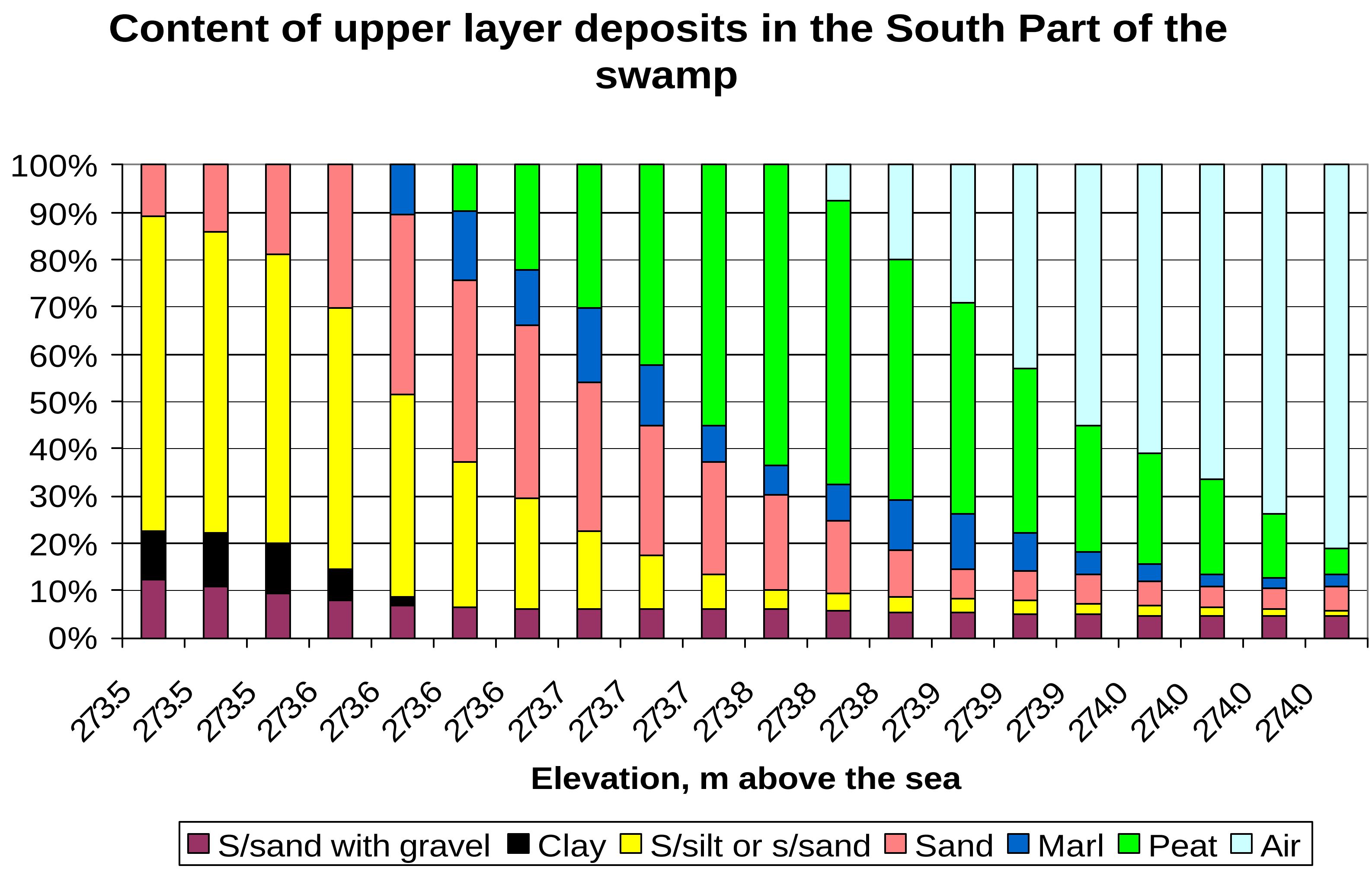

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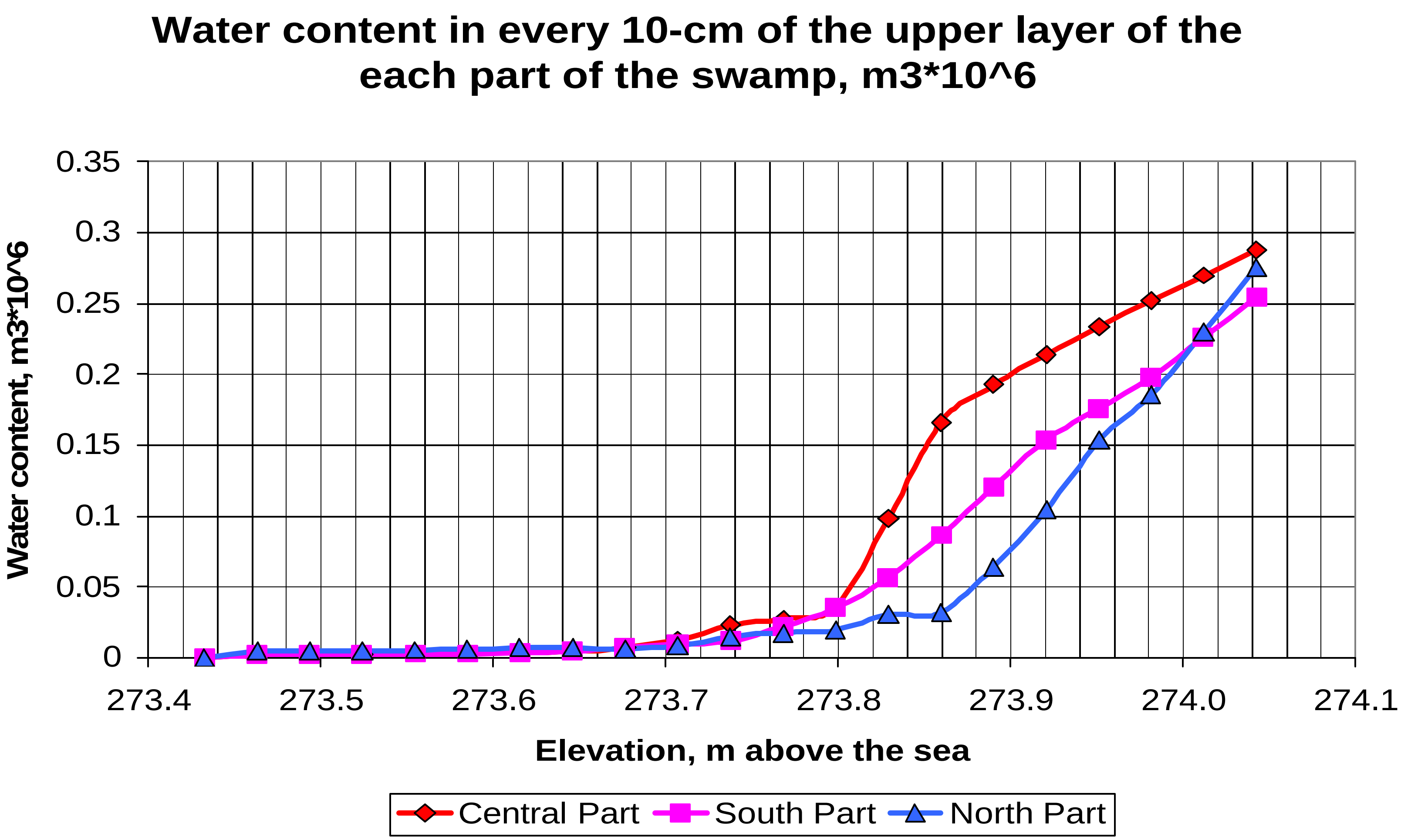

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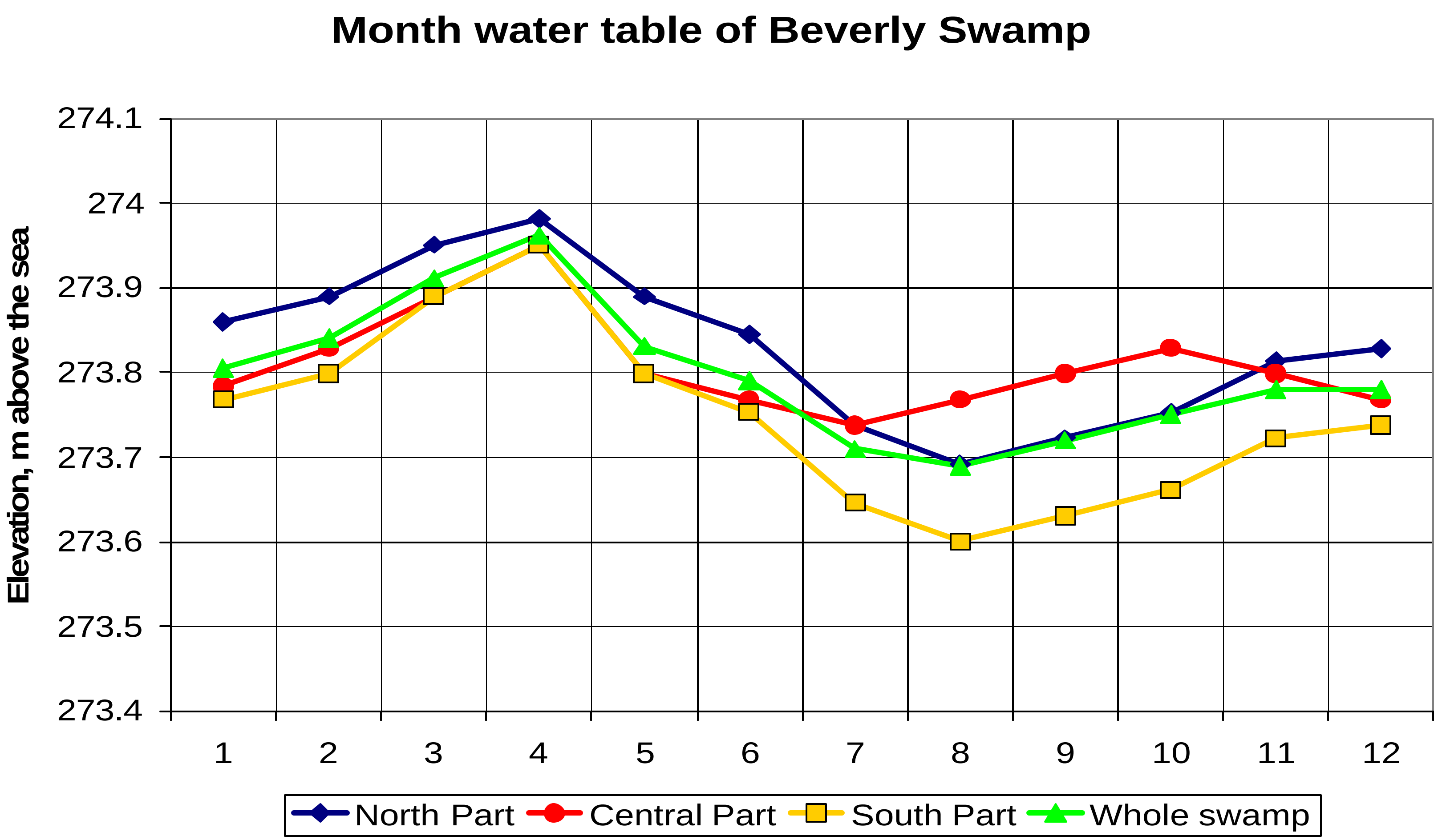

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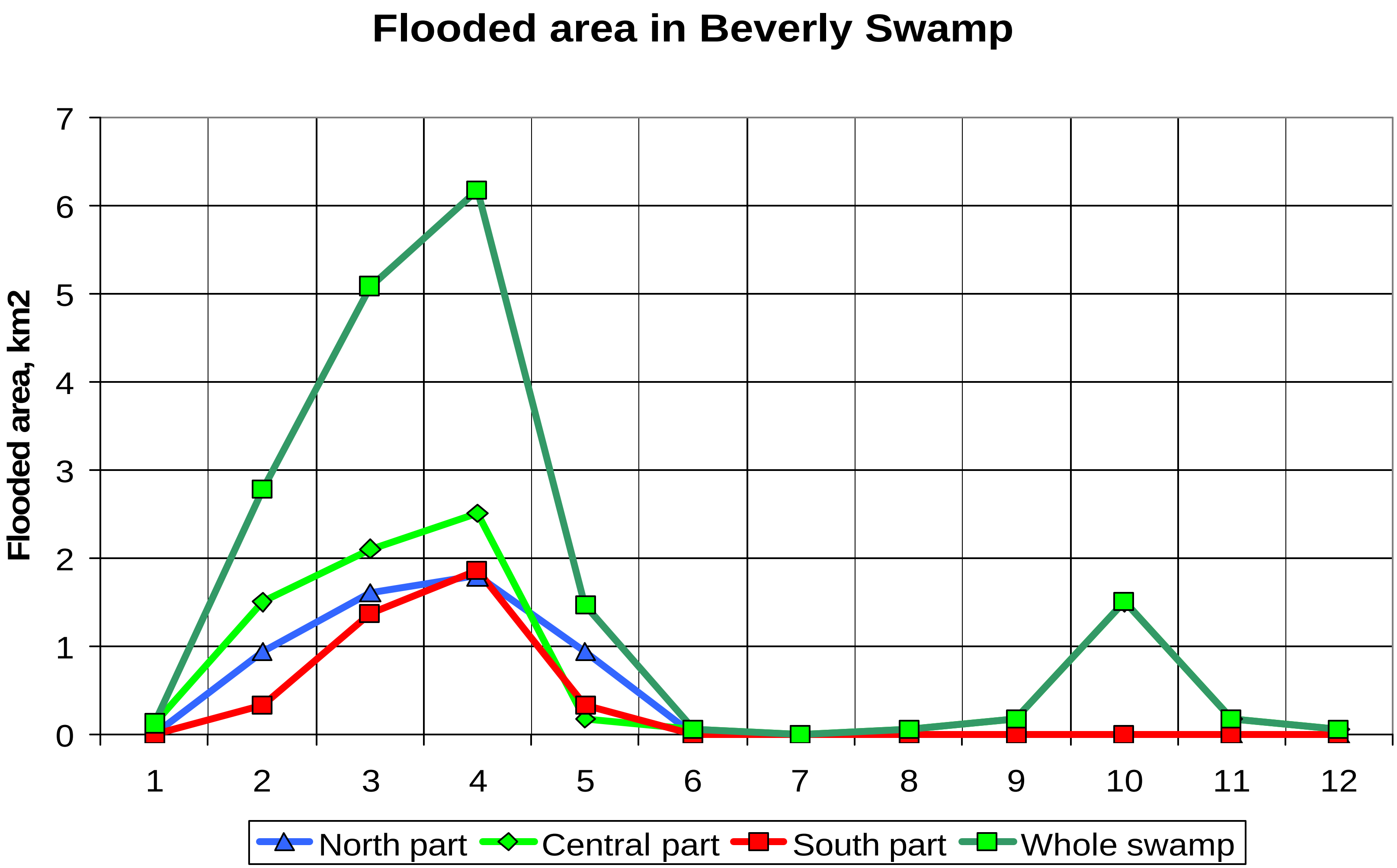

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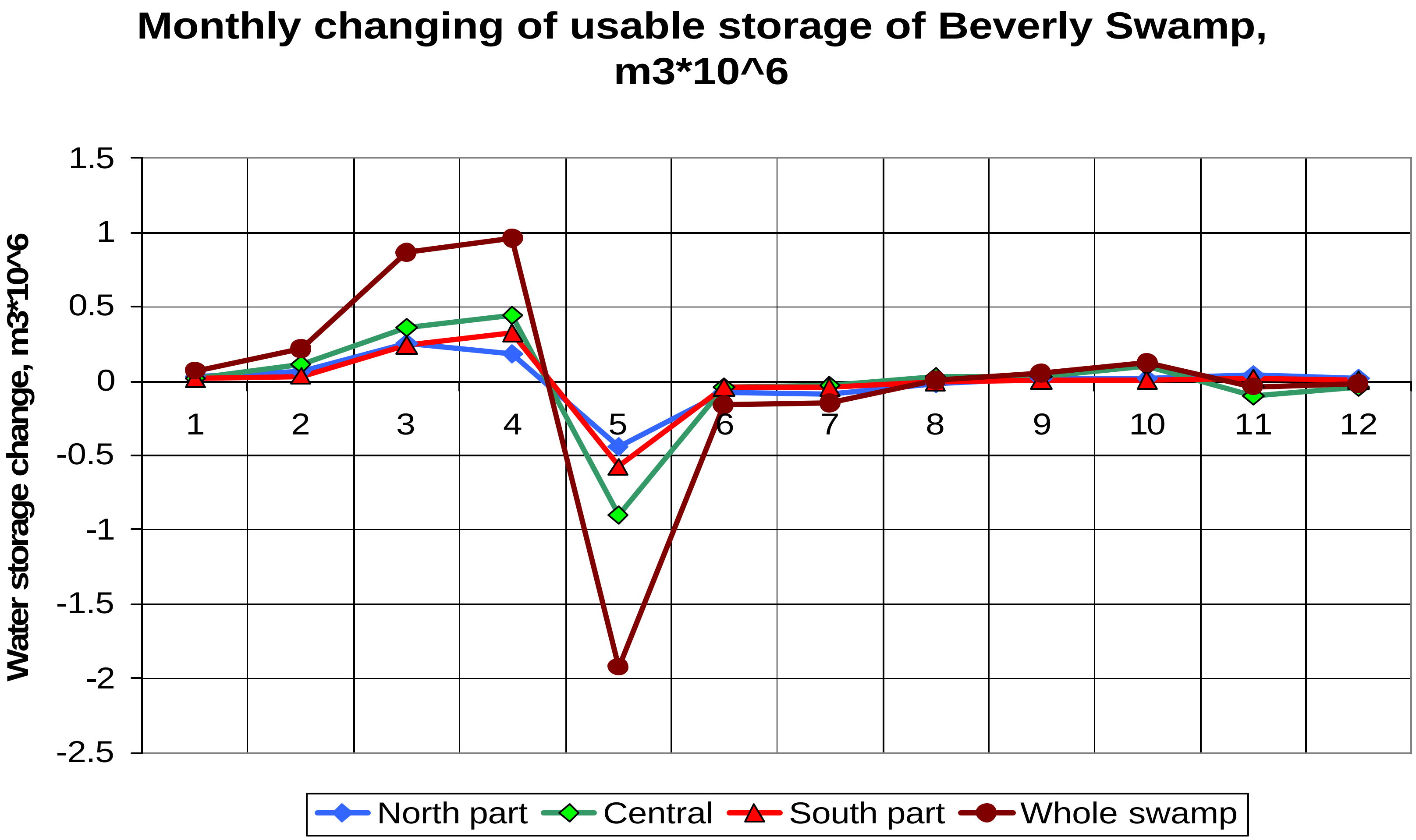

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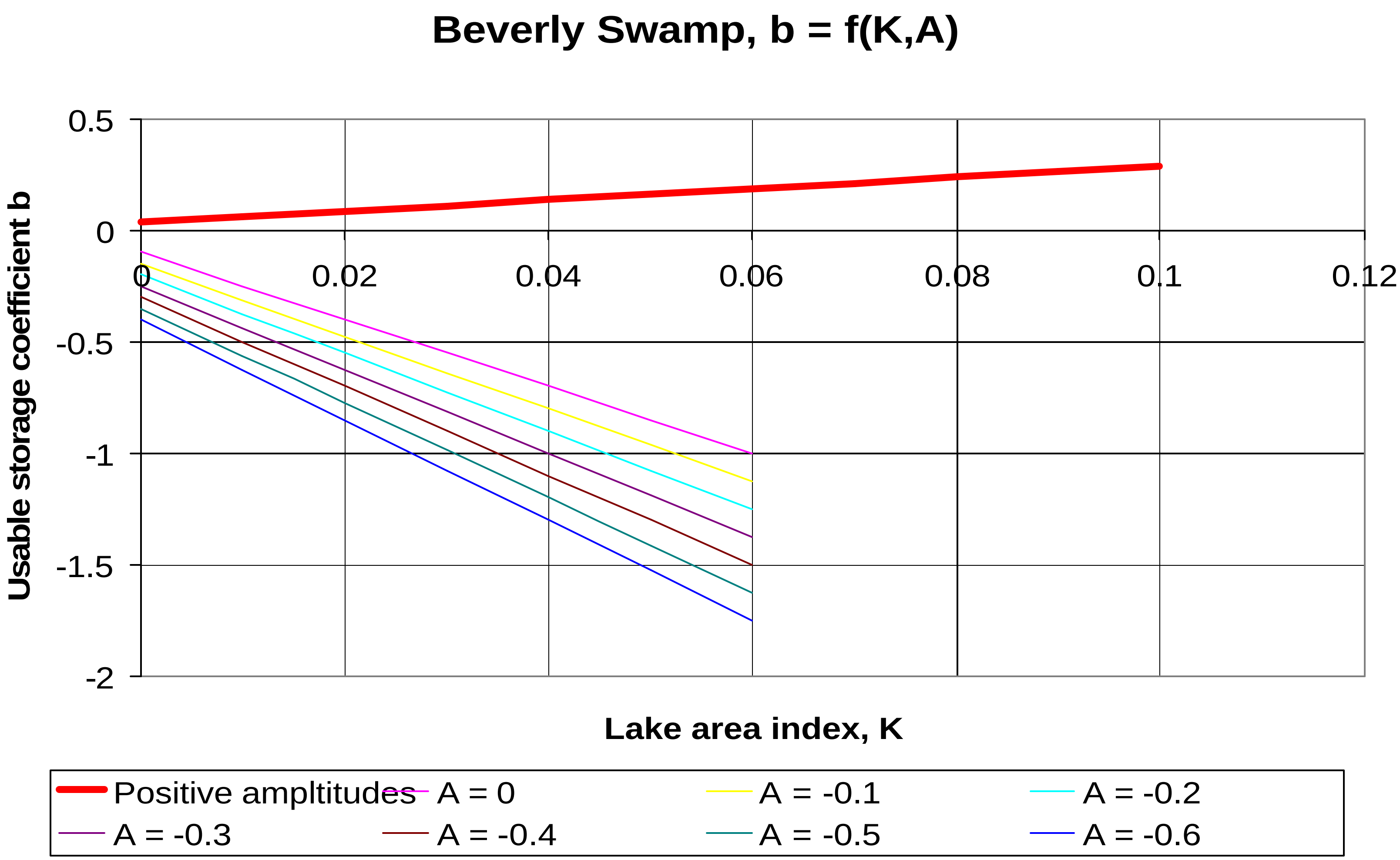

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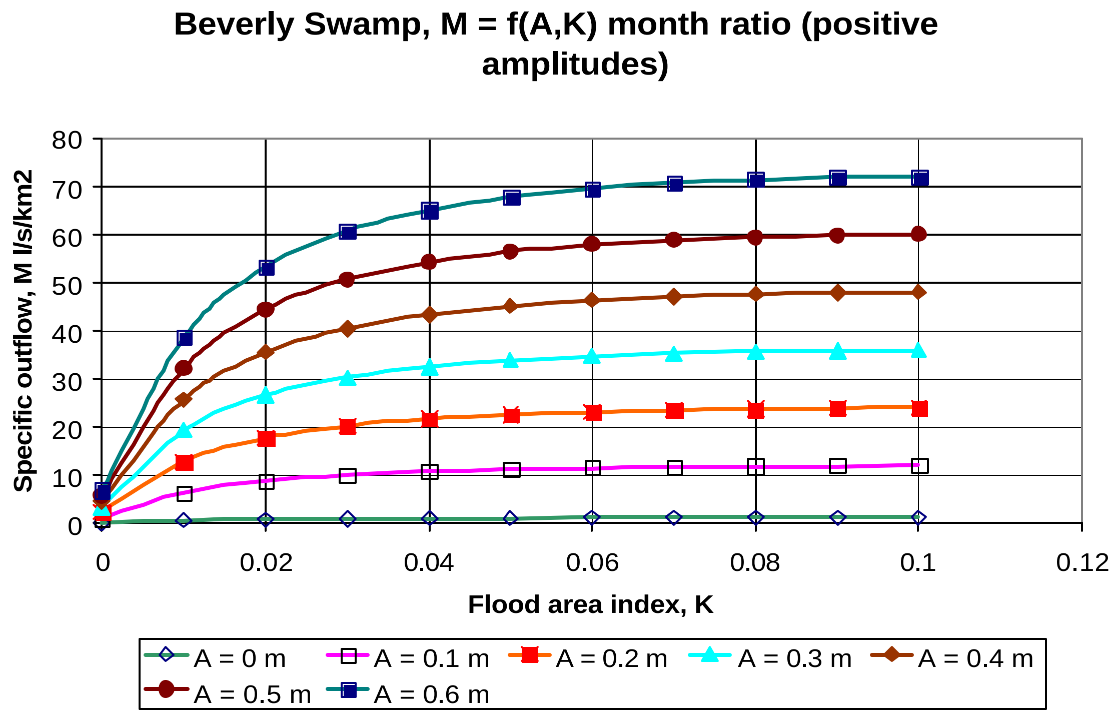

Fig. 28. M = f(A,K) monthly ratio for rising water table (amplitude is positive if the current month level is higher than the previous one).

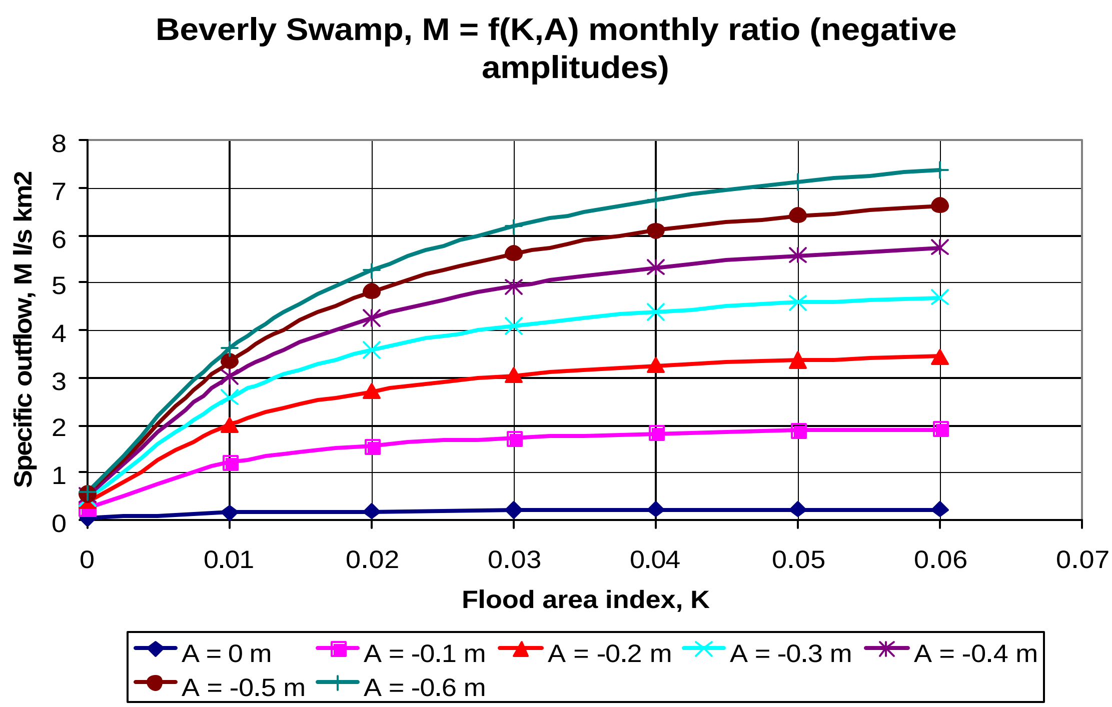

Fig. 29. M = f(A,K) monthly ratio for decreasing water table (amplitude is negative if the current month level is lower than the previous one).

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Table 1. Climate norms for Hamilton and Waterloo-Wellington climate stations (Environment Canada)

Hamilton (airport) 43'10-N 79'56-W/O 237m 1959-90

	Jan	Feb	March	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Year
Temperature, o C													
Daily Max	-2.6	-1.6	3.7	11.3	18.5	23.5	26.4	25.3	20.7	13.9	7.2	0.5	12.2
Daily Min	-10	-9.8	-4.6	1.2	7	12.2	15.1	14.4	10.5	4.7	-0.2	-6.7	2.8
Daily Mean	-6.2	-5.6	-0.4	6.3	12.9	17.9	20.8	19.9	15.6	9.3	3.5	-3.1	7.6
Extr Max	13.3	14.3	23.7	29.8	32.8	35	37.4	35.6	34.4	28.9	24.4	20.7	
Date	67/25	84/23	90/15	90/25	62/17	88/25	88/07	73/28	73/03	71/02	61/03	82/03	
Extr.Min	-27.8	-26.1	-22	-12.8	-3.9	1.7	5.6	1.1	-2.2	-7.8	-12.9	-26.8	
Date	76.18	76/02	80/02	72/07	66/10	72/11	61/05	65/30	74/23	65/29	87/21	80/25	
Precipitation													
Rainfall, mm	22.2	24.6	50.5	66.5	70.1	78.4	81	84.7	83.5	65.8	69.6	46.4	743
Snowfall, cm	41.8	32	22.3	7.3	0.5	0	0	0	0	1.1	9.8	37.6	152
Precipitation	61.3	53.5	73.7	74.3	70.7	78.4	81	84.7	83.5	66.3	80.2	82.8	890
W/S	0.094	0.090	0.104	0.107	0.120					0.045	0.108	0.097	
Extr Daily													
Rainfall, mm	27.9	54.1	31.1	42.7	39.9	66.6	107	90.8	55.5	54.9	53.6	56.8	
Date	65/24	90/22	80/21	76/25	69/18	84/17	89/26	81/08	84/13	73/29	62/09	90/29	
Snowfall, cm	43.2	27.4	24.2	29.2	11	0	0	0	0	23.6	16.4	35.6	
Date	66/22	84/28	87/31	79/09	89/07	90/30	90/31			62/25	86/20	69/23	
Precipitation	44.6	54.1	41.4	44.7	39.9	66.6	107	90.8	55.5	54.9	53.6	56.8	
Date	82/31	90/22	85/04	76/25	69/18	84/17	89/26	81/08	84/13	73/29	62/09	90/29	
Snow cover	10	6	1	0	0	0	0	0	0	0	1	6	
rain/snow ratio	0.36	0.46	0.69	0.90	0.99	1	1	1	1	0.99	0.87	0.56	

Waterloo-Wellington 43'27-N 80'23-W/O

	Jan	Feb	March	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Year
Temperature, o C													
Daily Max	-3.3	-2.5	2.9	11.2	18.6	23.2	26.1	24.8	20.1	13.2	6.3	-0.5	11.7
Daily Min	-11.4	-11.2	-6.1	0.4	6.3	10.7	13.6	12.6	8.5	2.9	-1.3	-7.6	1.5
Daily Mean	-7.3	-6.8	-1.5	5.8	12.5	17	19.9	18.7	14.3	8	2.5	-4	6.6
Extr Max	11.1	12.9	23.1	29.2	32	36.1	36	34.4	33.3	29.4	21.7	18.7	
Date	75/11	84/23	90/15	90/25	87/28	88/25	90/04	73/28	73/03	71/02	74/01	82/03	
Extr.Min	-31.9	-29.2	-25.4	-16.1	-3.9	-0.6	5	1.1	-3.7	-8.3	-13.7	-27.9	
Date	84/16	79/18	80/02	72/08	70/07	72/11	72/05	82/29	89/27	76/27	87/21	80/25	
Precipitation													
Rainfall, mm	20.2	26.5	49.2	64.4	75.8	79.5	90.4	93.3	89.6	69.8	71.8	43.1	774
Snowfall, cm	39.9	33.4	21.9	8.1	0.4	0	0	0	0	0.6	12.7	41	158
Precipitation	54.3	55.6	72.7	72.6	76.3	79.5	90.4	93.3	89.6	70.4	83.1	79.2	917
W/S	0.085	0.087	0.107	0.101	0.125					0.100	0.089	0.088	
Extr Daily													
Rainfall, mm	30.2	29.7	32.8	27.9	41.1	54.2	89.8	73.7	74.4	39.2	50.8	36.8	
Date	80/11	75/24	74/04	76/25	74/16	84/17	85/15	75/24	86/10	77/08	89/15	90/28	
Snowfall, cm	16.3	17.8	20.2	14	6	0	0	0	0	2	16.6	22.4	
Date	76/13	85/12	80/08	75/02	84/13	90/30				81/22	86/20	71/30	
Precipitation	30.4	31.6	53.8	36.6	41.1	54.2	89.8	73.7	74.4	39.2	50.8	36.8	
Date	80/11	85/12	76/02	76/25	74/16	84/17	85/15	75/24	86/10	77/08	89/15	90/28	
Snow cover	16	14	1	0	0	0	0	0	0	0	1	9	
rain/snow ratio	0.37201	0.47662	0.67675	0.88705	0.99345	1	1	1	1	0.99148	0.86402	0.54419	

Table 2. Measurements of Beverly Swamp and its parts.

Total area of the Swamp	– 8.4 km² (100%)	
Total open area		- 0.54 km² (6.4%)
Total forest area		- 7.86 km² (93.6%)
North part of the Swamp	- 2.98 km² (35.5% or 100%)	
Open area		0
Forest area		- 2.98 km² (35.5%)
Central part of the Swamp	– 2.83 km² (33.7% or 100%)	
Open area		- 0.35 km² (4.2% or 12.4%)
Forest area		- 2.48 km² (29.5% or 87.6%)
Euthrophied lake		- 0.7 km² (8.3% or 24.7%)
‘Bank’ area		- 2.13 km² (25.4%or 75.3%)
South part of the Swamp	– 2.6 km² (30.8% or 100%)	
Open area		- 0.19 km² (2.2% or 7.3%)
Forest area		- 2.41 km² (28.6% or 92.7%).

Table 3. Same-day measured discharges

Same-day measurements of the creek flow, 1975 ,cubm/s

Place	Fl+Sp		Main		Westover	
Subwatershed	45.3 km2		55 km2		63.5 km2	
units	cub.m/s	l/s km2	cub.m/s	l/s km2	cub.m/s	l/s km2
June, 18	0.43	9.49	0.28	5.09	0.317	4.99
June, 27	0.29	6.40	0.135	2.45	0.113	1.78
July, 17	0.32	7.06	0.128	2.33	0.271	4.27
October,18	0.67	14.8	0.68	12.4	0.771	12.1

Same-day estimations made in July 13, 1999

July,13,1999	0.074	1.634	0.036	0.655	0.054	0.850

Table 4. Drainage areas of Beverly Swamp and its parts

North Part of the swamp	
Fletcher Creek, swamp boarder	~37 km²
North Part, local drainage area	~ 3 km²
Fletcher Creek, confluence	~43 km²
Central Part of the swamp	
Spencer Creek, swamp boarder	~ 8.3 km²
Spencer Creek, confluence	~10 km²
Spencer Creek, Main stream (Concession 8)	~55 km²
Central Part, local drainage area	~1.2 km²
South Part of the swamp	
South Part, local drainage area	~ 4.5 km²
Beverly Swamp totally:	
Beverly Swamp with local drainage area	~17.1 km²
Spencer Creek, downstream boarder	~61.7 km²
Spencer Creek, Westover outlet	63.5 km²

Table 5. Specific yield of peat in different parts of Beverly Swamp

			North part	Central part hole'	Central part Tower site	South part
above surface	10-30	cm	0.97	0.95	0.97	0.97
(Welch, 1978)	0-10	cm	0.8	0.85	0.8	0.8
below surface	0-20	cm	0.15	0.3	0.07	0.15
(Crook, 1999)	25-45	cm	0.09	0.23	0.05	0.09
	50-80	cm	0.05	0.15	0.03	0.05

Table 6. Soil moisture deficit, mm

Depth (Z), m	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65
Moisture deficit (S), mm	3	6	9	13	18	23	29	35	40	45	51	57	63

Table 7. Water balance of Beverly Swamp, mm

			I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
		Precipitation, mm													
Valens	precipit., mm		59.7	53.1	70.36	71.12	71.63	68.07	68.33	70.61	67.82	73.69	77.72	71.37	823.52
	rain, mm		21.915	24.862	47.914	63.37	71.091	68.07	68.33	70.61	67.82	73.098	67.3	39.417	683.8
	snow, mm		37.785	28.238	22.446	7.7495	0.5386	0	0	0	0	0.5919	10.42	31.953	139.72
North			1	1	1	0.95	0.87	0.85	0.85	0.85	0.85	0.95	1	1	
0.355	P to ground, mm		59.7	53.1	70.36	67.564	62.318	57.86	58.081	60.019	57.647	70.006	77.72	71.37	765.74
	Ws/S		0.25	0.45	0.75	0.89	0						0	0.2	
	water eq.(Ws) mm		35	40	20	0	0						0	25	120
	to ground, mm		49.7	48.1	90.36	87.564	62.318	57.86	58.081	60.019	57.647	70.006	77.72	46.37	765.74
Centre			0.85	0.85	0.85	0.85	0.7	0.7	0.7	0.7	0.7	0.7	0.8	0.85	
0.337			50.745	45.135	59.806	61.775	52.806	50.181	50.373	52.054	49.997	54.324	62.176	60.665	650.04
	Ws/S		0.23	0.43	0.7	0.89							0.25	0.18	
	water eq.(Ws) mm		65	55	35	10	0						0	45	210
	to ground, mm		30.745	55.135	79.806	86.775	62.806	50.18	50.37	52.05	50	64.01	62.176	0	644.05
South			1	1	1	0.95	0.9	0.87	0.85	0.85	0.85	0.95	1	1	
0.308			59.7	53.1	70.36	67.824	64.99	59.867	58.829	60.792	58.39	70.274	77.72	71.37	773.21
	Ws/S		0.25	0.45	0.75	0.89							0	0.2	
	water eq.(Ws) mm		35	40	20	0	0						0	25	120
	to ground, mm		49.7	48.1	90.36	87.824	64.99	59.867	58.829	60.792	58.39	70.274	77.72	20	746.84
Beverly,	to ground, mm		43.312	50.471	86.803	87.378	63.305	55.89	55.713	57.571	55.299	68.068	72.482	22.621	718.91
totally	interception, mm		3.0178	2.6842	3.5567	5.9527	12.754	13.232	13.704	14.161	13.601	9.8929	5.2383	3.6078	101.4
	in snow, mm		45.11	45.055	25.055	3.37	0	0	0	0	0	0	0	31.74	150.33
		Outflow, mm													
Beverly			26.167	24.772	61.619	62.813	28.277	13.46	8.863	8.4409	12.644	20.68	31.406	30.809	329.95
		Ground water storage changing, mm													
North	table	cm	10	0	-10	-15	0	15	50	65	55	45	25	20	21.667
0.355	depth chang.	cm	-10	-10	-10	-5	15	15	35	15	-10	-10	-20	-5	
	storage ch.	mm	-15	-15	-80	-40	120	22.5	31.5	7.5	-5	-5	-18	-7.5	-4
Centre	table	cm	5	-5	-15	-30	0	10	20	10	0	-5	0	10	0
hole'	depth chang.	cm	-5	-10	-10	-15	30	10	10	-10	-10	-5	5	10	

				I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
0.083	storage ch.		mm	-15	-70	-85	-127.5	255	30	30	-30	-30	-40	40	30	-12.5
Centre	table		cm	10	0	-10	-15	0	15	50	65	55	45	25	20	21.667
bank'	depth chang.		cm	-10	-10	-10	-5	15	15	35	15	-10	-10	-20	-5	
0.254	storage ch.		mm	-7	-7	-85	-42.5	127.5	10.5	17.5	4.5	-3	-3	-10	-2.5	0
South	table		cm	10	0	-10	-15	0	15	50	65	55	45	25	20	21.667
0.308	depth chang.		cm	-10	-10	-10	-5	15	15	35	15	-10	-10	-20	-5	
	storage ch.		mm	-15	-15	-80	-40	120	22.5	31.5	7.5	-5	-7	-18	-7.5	-6
Beverly	water table		cm	8.315	-1.685	-11.69	-20.06	0	13.315	39.89	46.465	36.465	28.15	16.575	16.63	14.365
Beverly	storage ch.		mm	-12.97	-17.53	-81.69	-47.9	133.11	20.075	27.82	3.6255	-6.567	-8.013	-11.15	-3.118	-4.306
			Inflow, mm													
Beverly				26	25	62	63	37	24	19	22	25	33	35	34	405
			Changing in soil moisture storage (deficit), mm													
North	m a.s.l.	level		273.86	273.89	273.95	273.98	273.89	273.84	273.74	273.69	273.72	273.75	273.81	273.83	273.83
0.355	m	avg.depth		0.1	0	-0.1	-0.15	0	0.15	0.5	0.65	0.55	0.45	0.25	0.2	
	km2	Fwater		0	0.941	1.605	1.796	0.941	0	0	0	0	0	0	0	
	mm	deficit		6	0	0	0	0	9	45	63	51	40	18	13	
	mm	def. changing		-7	-6	0	0	0	9	36	18	-12	-11	-22	-5	0
Central	m a.s.l.	level		273.78	273.83	273.89	273.95	273.8	273.77	273.74	273.77	273.8	273.83	273.8	273.77	273.81
0.337	m	avg.depth		0.05	-0.03	-0.16	-0.33	0	0.1	0.2	0.1	0	-0.03	0	0.1	
	km2	F.water		0.122	1.5	2.103	2.513	0.183	0.06	0	0.06	0.183	1.5	0.183	0.06	
	mm	deficit		3	0	0	0	0	6	13	6	0	0	0	6	
	mm	def. changing		-3	-3	0	0	0	6	7	-7	-6	0	0	6	0
South	m a.s.l.	level		273.77	273.8	273.89	273.95	273.8	273.75	273.65	273.6	273.63	273.66	273.72	273.74	273.75
0.308	m	avg.depth		0.1	0	-0.09	-0.22	0	0.15	0.5	0.65	0.55	0.45	0.25	0.2	
	km2	F.water		0	0.335	1.375	1.855	0.335	0	0	0	0	0	0	0	
	mm	deficit		6	0	0	0	0	9	45	63	51	40	18	13	
	mm	def. changing		-7	-6	0	0	0	9	36	18	-12	-11	-22	-5	0
Whole swamp		mm		-5.652	-4.989	0	0	0	7.989	26.227	9.575	-9.978	-7.293	-14.59	-1.293	-2E-15
Balance residual			Evapotranspiration, mm													
		mm		27.543	30.861	9.0561	45.095	216.83	106.67	132.51	97.37	63.631	70.704	55.574	38.41	894.26

Table 8. The areas occupied by each deposit, km2

North part

Elevation, m a.s.l.	Total area km2	Silty sand +grav. km2	Clay km2	Sandy/silt or silty/sand km2	Sand km2	Marl km2	Peat km2	Air km2
273.43	1.87	0.296	0.350	0.874	0.350	0	0	0
273.46	1.93	0.264	0.423	0.780	0.463	0	0	0
273.49	1.98	0.245	0.458	0.808	0.469	0	0	0
273.52	2.04	0.180	0.374	0.968	0.517	0	0	0
273.55	2.09	0.139	0.165	1.013	0.773	0	0	0
273.59	2.15	0.113	0	0.893	1.144	0	0	0
273.62	2.2	0.110	0	0.770	1.320	0	0	0
273.65	2.28	0.084	0	0.555	1.230	0.410	0	0
273.68	2.36	0.096	0	0.299	1.210	0.515	0.240	0
273.71	2.43	0.094	0	0.248	1.109	0.189	0.790	0
273.74	2.51	0.093	0	0	1.039	0.093	1.284	0
273.77	2.59	0.093	0	0	0.856	0.069	1.573	0
273.80	2.67	0.092	0	0	0.596	0.264	1.719	0
273.83	2.75	0.091	0	0	0.274	0.479	1.906	0
273.86	2.82	0.090	0	0	0.282	0.485	1.963	0
273.89	2.9	0.090	0	0	0.314	0.213	1.344	0.941
273.92	2.98	0.077	0	0	0.285	0.186	1.282	1.150
273.95	3.06	0.075	0	0	0.214	0.107	1.059	1.605
273.98	3.14	0.074	0	0	0.221	0.074	0.977	1.796
274.01	3.22	0.072	0	0	0.227	0.072	0.299	2.549
274.04	3.3	0.071	0	0	0.344	0.081	0.040	2.763

South part

Elevation, m a.s.l.	Total area km2	Silty sand +grav. km2	Clay km2	Sandy/silt or silty/sand km2	Sand km2	Marl km2	Peat km2	Air km2
273.43	1.39	0.180	0.130	0.950	0.130	0	0	0
273.46	1.46	0.170	0.160	0.955	0.175	0	0	0
273.49	1.52	0.155	0.185	0.940	0.240	0	0	0
273.52	1.58	0.130	0.180	0.930	0.340	0	0	0
273.55	1.65	0.120	0.065	0.835	0.630	0	0	0
273.59	1.71	0.110	0	0.600	0.645	0.355	0	0
273.62	1.8	0.115	0	0.485	0.700	0.160	0.340	0
273.65	1.89	0.110	0	0.385	0.640	0.280	0.475	0
273.68	1.97	0.120	0	0.250	0.585	0.320	0.695	0
273.71	2.06	0.125	0	0.210	0.525	0.185	1.015	0
273.74	2.15	0.130	0	0.090	0.485	0.145	1.300	0
273.77	2.24	0.130	0	0.085	0.410	0.130	1.485	0
273.80	2.33	0.130	0	0.080	0.300	0.210	1.275	0.335
273.83	2.41	0.130	0	0.075	0.155	0.300	1.145	0.605
273.86	2.5	0.130	0	0.070	0.160	0.275	1.040	0.825
273.89	2.59	0.130	0	0.065	0.170	0.125	0.725	1.375
273.92	2.72	0.130	0	0.060	0.160	0.115	0.700	1.555

Table 8. The areas ocupied by each deposit, km2

(continuing)

Elevation, m a.s.l.	Total area	Silty sand +grav.	Clay	Sandy/silt or silty/sand	Sand	Marl	Peat	Air
	km2	km2	km2	km2	km2	km2	km2	km2
273.95	2.86	0.130	0	0.055	0.130	0.085	0.605	1.855
273.98	2.99	0.135	0	0.050	0.130	0.070	0.575	2.030
274.01	3.12	0.140	0	0.045	0.135	0.075	0.240	2.485
274.04	3.26	0.145	0	0.040	0.195	0.080	0.110	2.690

Central part

Elevation, m a.s.l.	Total area	Sandy/silt or silty/sand	Sand	Marl	Peat	Air
	km2	km2	km2	km2	km2	km2
273.43	1.29	1.217	0.073	0	0	0
273.46	1.41	1.340	0.070	0	0	0
273.49	1.53	1.477	0.053	0	0	0
273.52	1.66	1.580	0.080	0	0	0
273.55	1.78	1.677	0.067	0.037	0	0
273.59	1.9	1.773	0.063	0.050	0.013	0
273.62	1.99	1.787	0.063	0.053	0.087	0
273.65	2.09	1.823	0.060	0.047	0.160	0
273.68	2.18	1.540	0.060	0.033	0.547	0
273.71	2.27	0.900	0.057	0.023	1.290	0
273.74	2.37	0.747	0.050	0.013	1.560	0
273.77	2.46	0.740	0.050	0.013	1.597	0
273.80	2.56	0.637	0.040	0.007	1.693	0.183
273.83	2.65	0.520	0.030	0	0.600	1.500
273.86	2.74	0.453	0.023	0	0.450	1.813
273.89	2.83	0.397	0.017	0	0.313	2.103
273.92	2.97	0.373	0.017	0	0.270	2.310
273.95	3.11	0.347	0.017	0	0.233	2.513
273.98	3.25	0.327	0.013	0	0.200	2.710
274.01	3.39	0.307	0.013	0	0.170	2.900
274.04	3.53	0.287	0.010	0	0.140	3.093

Table 9. Content of deposits (m3*10^6) in each part of the swamp

Elevation of upper boarder of 10-cm layer	Volume of layer m3/10^6	Silty sand +gravel. m3/10^6	Clay m3/10^6	Sandy/silt or silty/sand m3/10^6	Sand m3/10^6	Marl m3/10^6	Peat m3/10^6	Air m3/10^6	Sum of air's volume m3/10^6
273.43							**North part**		
273.46	0.150	0.022	0.031	0.065	0.032	0	0	0	0
273.49	0.157	0.019	0.035	0.064	0.037	0	0	0	0
273.52	0.163	0.016	0.034	0.072	0.037	0	0	0	0
273.55	0.170	0.013	0.022	0.082	0.050	0	0	0	0
273.59	0.177	0.011	0.007	0.080	0.080	0	0	0	0
273.62	0.185	0.009	0	0.071	0.105	0	0	0	0
273.65	0.194	0.008	0	0.057	0.111	0.018	0	0	0
273.68	0.203	0.008	0	0.037	0.107	0.041	0.011	0	0
273.71	0.212	0.008	0	0.024	0.103	0.031	0.046	0	0
273.74	0.222	0.008	0	0.011	0.096	0.013	0.093	0	0
273.77	0.231	0.008	0	0	0.086	0.007	0.130	0	0
273.80	0.241	0.008	0	0	0.066	0.015	0.151	0	0
273.83	0.250	0.008	0	0	0.040	0.034	0.167	0	0
273.86	0.259	0.008	0	0	0.026	0.045	0.180	0	0
273.89	0.268	0.008	0	0	0.028	0.033	0.155	0.044	0.044
273.92	0.280	0.008	0	0	0.028	0.019	0.125	0.100	0.144
273.95	0.294	0.007	0	0	0.024	0.014	0.114	0.134	0.278
273.98	0.308	0.007	0	0	0.022	0.009	0.101	0.169	0.447
274.01	0.322	0.007	0	0	0.023	0.007	0.064	0.220	0.667
274.04	0.336	0.007	0	0	0.029	0.008	0.017	0.274	0.941
273.43							**South part**		
273.46	0.143	0.018	0.015	0.095	0.015	0	0	0	0
273.49	0.149	0.016	0.017	0.095	0.021	0	0	0	0
273.52	0.155	0.014	0.016	0.094	0.029	0	0	0	0
273.55	0.162	0.013	0.011	0.088	0.049	0	0	0	0
273.59	0.168	0.012	0.003	0.072	0.064	0.018	0	0	0
273.62	0.176	0.011	0	0.054	0.067	0.026	0.017	0	0
273.65	0.185	0.011	0	0.044	0.067	0.022	0.041	0	0
273.68	0.193	0.012	0	0.032	0.061	0.030	0.059	0	0
273.71	0.202	0.012	0	0.023	0.056	0.025	0.086	0	0
273.74	0.211	0.013	0	0.015	0.051	0.017	0.116	0	0
273.77	0.220	0.013	0	0.009	0.045	0.014	0.139	0	0
273.80	0.229	0.013	0	0.008	0.036	0.017	0.138	0.017	0.017
273.83	0.237	0.013	0	0.008	0.023	0.026	0.121	0.047	0.064
273.86	0.246	0.013	0	0.007	0.016	0.029	0.109	0.072	0.135
273.89	0.255	0.013	0	0.007	0.017	0.020	0.088	0.110	0.245
273.92	0.266	0.013	0	0.006	0.017	0.012	0.071	0.147	0.392
273.95	0.279	0.013	0	0.006	0.015	0.010	0.065	0.171	0.562
273.98	0.293	0.013	0	0.005	0.013	0.008	0.059	0.194	0.757
274.01	0.306	0.014	0	0.005	0.013	0.007	0.041	0.226	0.982
274.04	0.319	0.014	0	0.004	0.017	0.008	0.018	0.259	1.241

Table 9. Content of deposits (m3*10^6) in each part of the swamp

(continuing)

Elevation of upper boarder of 10-cm layer	Volume of layer m3/10^6	Silty sand +grav. m3/10^6	Clay m3/10^6	S/silt or s/sand m3/10^6	Sand m3/10^6	Marl m3/10^6	Peat m3/10^6	Air m3/10^6	Sum of air's volume m3/10^6
273.43							**Central part**		
273.46	0.135	0	0	0.128	0.007	0	0	0	0
273.49	0.147	0	0	0.141	0.006	0	0	0	0
273.52	0.160	0	0	0.153	0.007	0	0	0	0
273.55	0.172	0	0	0.163	0.007	0.002	0	0	0
273.59	0.184	0	0	0.173	0.007	0.004	0.001	0	0
273.62	0.195	0	0	0.178	0.006	0.005	0.005	0	0
273.65	0.204	0	0	0.181	0.006	0.005	0.012	0	0
273.68	0.214	0	0	0.168	0.006	0.004	0.035	0	0
273.71	0.223	0	0	0.122	0.006	0.003	0.092	0	0
273.74	0.232	0	0	0.082	0.005	0.002	0.1425	0	0
273.77	0.242	0	0	0.074	0.005	0.001	0.158	0.003	0.003
273.80	0.251	0	0	0.069	0.005	0.001	0.165	0.012	0.015
273.83	0.261	0	0	0.058	0.004	0.000	0.115	0.084	0.099
273.86	0.270	0	0	0.049	0.003	0	0.053	0.166	0.265
273.89	0.279	0	0	0.043	0.002	0	0.038	0.196	0.461
273.92	0.290	0	0	0.039	0.002	0	0.030	0.220	0.681
273.95	0.304	0	0	0.036	0.002	0	0.025	0.241	0.922
273.98	0.318	0	0	0.034	0.002	0	0.022	0.261	1.183
274.01	0.332	0	0	0.032	0.001	0	0.019	0.281	1.463
274.04	0.346	0	0	0.030	0.001	0	0.016	0.300	1.763

Table 10. Water content of Beverly Swamp in upper layer,

m3*10^6 (starting from 273.6m)

	North	Sum	Central	Sum	South	Sum
273.59	0.006	0.026	0.003	0.014	0.003	0.013
273.62	0.007	0.033	0.004	0.018	0.004	0.017
273.65	0.007	0.040	0.005	0.023	0.004	0.021
273.68	0.007	0.047	0.007	0.030	0.007	0.029
273.71	0.009	0.056	0.012	0.042	0.010	0.038
273.74	0.015	0.071	0.023	0.065	0.012	0.050
273.77	0.018	0.088	0.028	0.093	0.022	0.072
273.80	0.019	0.108	0.036	0.129	0.035	0.108
273.83	0.030	0.138	0.098	0.227	0.057	0.164
273.86	0.032	0.170	0.166	0.393	0.086	0.251
273.89	0.064	0.234	0.193	0.586	0.121	0.371
273.92	0.104	0.338	0.214	0.800	0.154	0.525
273.95	0.153	0.491	0.233	1.033	0.176	0.701
273.98	0.185	0.677	0.252	1.285	0.198	0.899
274.01	0.229	0.906	0.270	1.555	0.226	1.124
274.04	0.275	1.181	0.288	1.843	0.254	1.379

Table 11. Flooded area and usable storage of Beverly Swamp, km2

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Elevations m a.s.l	273.78	273.83	273.89	273.95	273.8	273.77	273.74	273.77	273.86	273.83	273.8	273.77
Area cove-red by water km2	0.122	1.5	2.103	2.513	0.183	0.06	0	0.06	0.183	1.5	0.183	0.06
Lake area index, K	0.002	0.043	0.076	0.091	0.023	0.001	0	0.001	0.003	0.024	0.003	0.001
Usable storage, m3*10^6	0.072	0.215	0.862	0.962	-1.922	-0.162	-0.151	0.003	0.052	0.121	-0.035	-0.015