THE INFLUENCE OF PONDS ON DISSOLVED OXYGEN IN SMALL RIVERS OF BERRY (FRANCE)

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ABSTRACT. The influence of ponds on dissolved oxygen in small rivers of Berry (France). Water temperature and oxygen saturation are two major indicators of water quality in surface hydrology. Geographical and cartographic studies about ponds of Central France did no exist until now. During two years, we measured dissolved oxygen using a hand oximeter upstream and downstream of three ponds in the headwaters of the Loire basin. Our results show that oxygen saturation depends on equipments located before and behind the dam, and upstream and downstream: spillways, outlets with a monk, diversion channel, artificial reoxygenation weirs and so on. In some cases (low water quality upstream, existence of weir), relative and absolute saturation of dissolved oxygen increases downstream of ponds.

Keywords: limnogeography, pond, dissolved oxygen, water temperature, headwaters.

1. INTRODUCTION AND STUDY SITE: A HEADWATER REGION WITH NUMEROUS PONDS

According to the French standards, which evolved and diversified since 1970 (Genin and al., 2003), the quality of the internal freshwater is estimated in several classes, which the construction bases on a certain number of official indicators defined by SEQ water. The principal indicators are the oxygen (in absolute concentration, in biological demand and in chemical demand), the permanganate index, the dissolved organic carbon, the compounds of the nitrogen and the phosphorus, the suspended matter, the turbidity, the pH, the chlorophyll a+. The standards are made for the running waters and the artificial water reservoirs are generally considered as troublemakers of this quality. The French bibliography of comparison between the values of dissolved oxygen in the upstream and in the entrance of a pond, or greater water impoundment, is widely based on the works of the professional circles of the fishing, the fish farming, the aquaculture. These internal reports often remind that "the content of dissolved oxygen of a stream is generally lower downstream of a water area, because of warmer waters, the inertia of the mass of water and by the degradation of organic fractions" (Trintignac and Kerleo, 2004, p. 18), but some contrary claims are there too. As for the international scientific works which deal with dissolved oxygen of rivers, they are

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a result of the researchers in “hard sciences” who are attached preferentially to the modeling and to the time scales (Rickert, 1984, Guasch *and al*., 1998, Villeneuve and *al*., 2006). Some of them take into account certainly the spatial dimension and the evolution from upstream to downstream, moreover most often in a modeling approach (Marzolf and al., 1994). Research in geography which take into account in detail the oxygenation of the water areas are very rare in France, concentrate instead on the lakes, but they don’t really exist on the ponds and, still less, on the influence of ponds on the oxygenation of the hydrographical network (water system). In this paper we propose a resolutely empirical approach and based on geographic and cartographic treatment of field measurements.

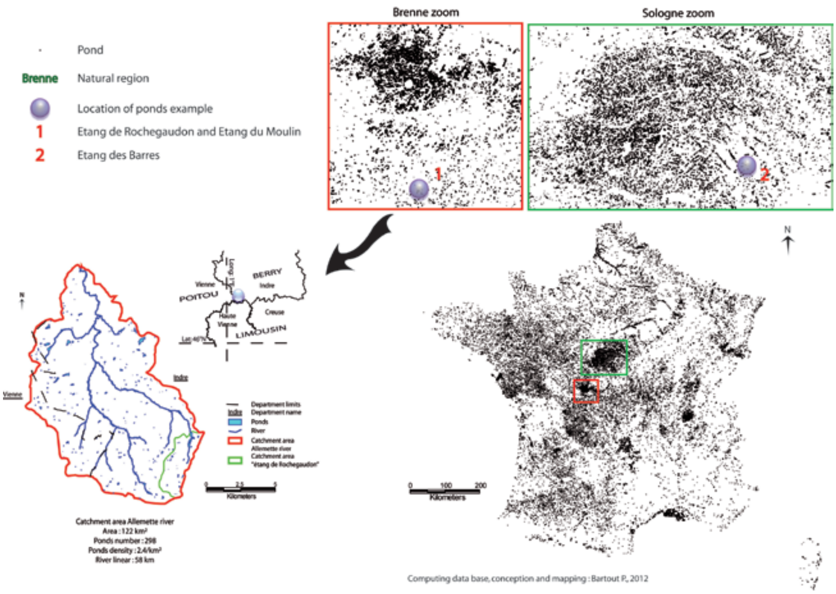

Fig. 1. ***The location of study sites and Berry’s pond regions in France***

The choice of the studied ponds rests at first on their equipment of evacuation or distribution of water. Because the French authorities suggest that the diversion is the equipment which decreases most the effects of ponds on the hydrographic network, but concern only 8.2 % of ponds (panel of 9000 ponds in Limousin and Berry, Touchart and Bartout, 2011), it would be logical to privilege the scientific study. Nevertheless, despite some early works of the professional circle, the scientific researches focused on ponds with diversion are rare. We had previously studied the question of the water temperature of ponds with diversion, by distinguishing the water area by-passed by a channel and water area situated on the channel (Touchart and Bartout, 2011); it seems important to add to it the factor of the dissolved oxygen. The other major criterion of choice of the study sites was the position in the basin and on the river linear, on one hand at the head of pond or on the higher Strahler rank, on the other hand in chain or isolated. The crossing of these criteria led to study the chain of the ponds of Moulin (3.28 ha) and of Rochegaudon (7.83 ha) blocking a rank 0 and the isolated pond of Barres (16.40 ha) situated on a more important river. The pond of Moulin is by-passed by a diversion, while the Barres is on the diversion itself.

France counts (in 2007) 251.289 ponds (natural and artificial, continental and littoral), that is a density of 0.46 pond by km², a stagnucity, is to say the part in water of ponds of a territory, of 0.48 % and an average size of 1.05 ha.

The "Region Centre", count to it only 34.646 ponds, is 13.8 % of the totality of the French ponds, while it occupies only 7.2 % of the French territory (Brenne and Sologne are two of the three bigger concentrations of ponds of France). Its density of ponds is thus near the double of the national average with 0.88 pond by km². Finally, its stagnucity is 1.04 %, is more of double of the national average, what is not the case of the average size of ponds because this one is only 1.18 ha. On the scale of Berry, we have 12.603 ponds, with a density of 0.83 pond by km² and a stagnucity of 1.19 %, slightly superior to that of the "Region Centre" (fig. 1).

Considering the figures of the density and the stagnucity, Berry's ponds are much bigger than the French standard with 1.43 ha. With their respective surfaces of 3.28, 7.83, 16.40 ha, ponds selected for this research are fairly large size and susceptible to have a measurable effect on the hydrographic network.

2. METHODS: DIRECT MEASUREMENTS OF WATER QUALITY AND GEOGRAPHIC SPATIALIZATION

The choice was made to measure the instantaneous concentrations of dissolved oxygen in water, and not the Biological Oxygen Demand in five days nor the Chemical Oxygen Demand. Three reasons justify this choice. In the first place, such measures are easy to realize and the technical maintenance of equipments is directly made by the first author (change of the membranes of the sensors, calibration, etc.). However this work is a geographical study, concentrating on the spatial and cartographic questions and making a particular effort on the follow up from upstream to downstream of the river linear using a large number of measurement points, as well as on the statements in the water of ponds and in the hydraulic equipments (Measures of the oxygen inside the diversions, at the exit of the monk, at the confluences of mixtures of waters, etc.). In the second place, the simplicity of the values of instantaneous concentration of oxygen expressed in milligrams by litre and relative saturations expressed in percentage is very meaningful for the owners and the managers of ponds and for the elected representatives of local authorities, allowing a more direct utility of the scientific research to the land-use planning and a better reception of the recommendations of research-advice. In the third place, the values of dissolved oxygen are in direct link with the temperature of the water (Truesdale *et al*., 1955, Hitchman, 1978, Butcher and Covington, 1995), which is the area of research of the first author.

The measures of oxygen in the river system of Allemette and the ponds of Moulin and Rochegaudon were realized once a month during two years (2009-2011) by Laurent Touchart. These measures are always made at the same moment (between 15 and 16 h) using a manual oximeter *197i* of *WTW*. The probe is a *CellOx 325*, which allows a precision better than that of the probes *DurOx*. The absolute concentrations of dissolved oxygen are transformed to relative saturations according to a correlation which based on the temperature of the water (Hitchman type equation). The measures of oxygen in the river system of Sauldre and the pond of Barres were realized once a week during four months (from February till May, 2011) by Ingrid Brière. These measures are made by using a multi-parameter probe *HI 9828* of *Hanna*, whose the measure of oxygen forms one of three sensors.

The values of dissolved oxygen can be crossed with many new measures of temperatures of the water, realized since 2007 in the basin of the Petite Sauldre and since 2009 in the basin of Allemette. All the measures of temperature are taken on the ground by Laurent Touchart, by using three instruments: i) The thermometers recorders *Tinytag Data Loggers* with probe internal piezoelectric, programmed to take the temperature of the water every hour, ii) the thermal probe of the manual oximeter, iii) a thermometer platinum with a very high precision, which serves us as reference; it is a resistance thermometer *Lufft C100* with Pt100 sensor 4-wire. The average gap of precision between a thermometer recorder and the thermometer platinum is 0.37 °C (Touchart and Bartout, 2010). The average deviation between the thermal probe of the oximeter *WTW* and the thermometer platinum is 0.23 °C.

The geographical approach relies at first on the number of sites of measure, distributed on the river linear and in ponds. The basin of Allemette includes 15 measurement points of the oxygen: 2 on the creek in upstream to the chain of ponds, 4 in channels situated between both ponds (diversion and canal downstream from the monk), 5 inside ponds (1 in the pond of Moulin, 3 in the pond of Rochegaudon, 1 in the reserve separated from the pond of Rochegaudon), 4 on the river downstream of the chain of ponds (at 10 m, 2250 m, 3275 m and 6550 m downstream of the dam). The basin of Sauldre includes 16 measurement points of the oxygen, 6 to quantify the influence of the pond des Barres on the Petite Sauldre and 10 to study two ponds of a small size situated not far. The geographical methodology strictly speaking expresses by maps built from the following factors: on one hand the systematic comparison between the upstream and the downstream from a point to the other one (calculation of gradients by 100 m of linear, use of the method of change of sign of the derivative to determine the point of the outlet where the river adjustment removed the influence of the pond), on the other hand the law of mixtures.

3. RESULTS: THE IMPACT OF PONDS ON RIVERS

The chain of two ponds of the Moulin and Rochegaudon was followed on two annual complete cycles. It is this example which will be taken as reference for the long-term averages. It is located in a hydrographic network with low-quality of waters, that of the Allemette river. On average of all the data (all the spatial data on 15 measurement sites and all the temporal data), the hydrographic network of Allemette presents the following characteristics: The average concentration in dissolved oxygen is 3.53 $mg.l^{-1}$,the relative average saturation in dissolved oxygen is 35.72 % and the average temperature of water is 15.5 °C. According to the French standards, the average value of dissolved oxygen resulting from our measurements places the entire network of Allemette in the fourth class ("bad quality", "orange class") on five of the decreasing quality (between 3 et 4 mg.l^{-1}O_2).

The site of the hydrographic network which has the lowest annual average concentration of dissolved oxygen is the one situated just upstream to the chain of ponds. The site which has the highest value is the one which is just downstream of the ponds, below the dam. The measurement sites located a few hectometers or kilometers downstream to ponds present intermediate values. Manifestly, the chain of ponds of Moulin and Rochegaudon increases significantly the oxygenation of the river and this one loses gradually a part of this gain along the river linear located downstream.

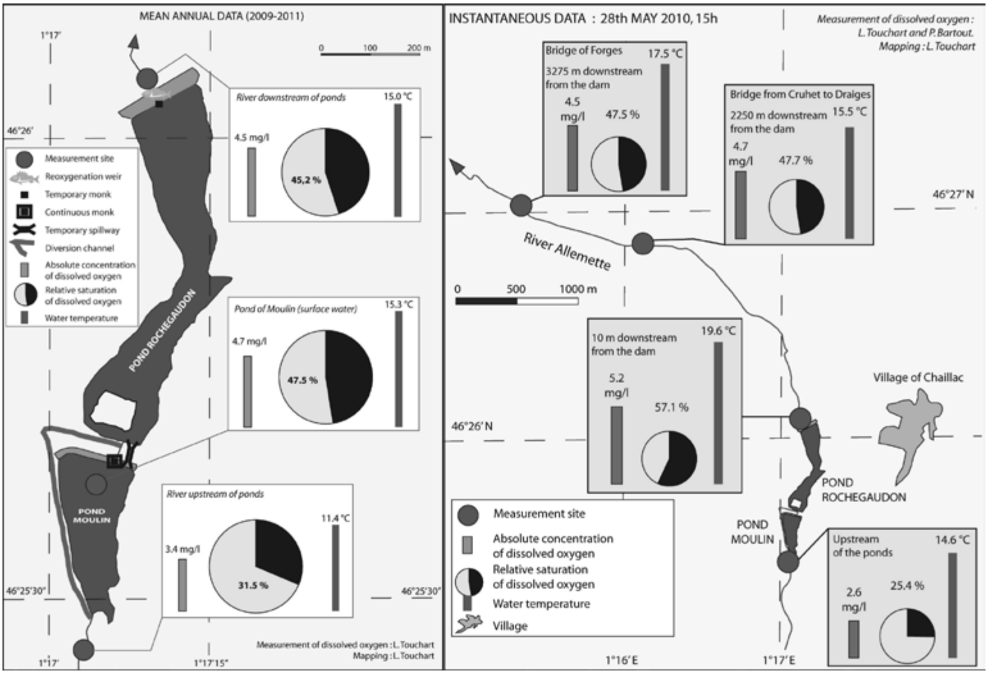

Fig. 2. ***Oxygen concentration upstream, downstream and within Rochegaudon's pond chain***

At all seasons, the dissolved oxygen values are higher at the exit of the ponds than at the entrance. The gap is small in cold season. It is maximal at the end of the spring. The case of May 28th, 2010 is exemplary in this respect (fig. 2). The oxygenation of the river is increased bay 2.0 times between the upstream and the downstream in terms of absolute concentration (from 2.6 to 5.2 mg.l^{-1}). The relative saturation in oxygen increases of 2.2 times (from 25.4 to 57.1 %), because, at the same time, the chain of ponds warms the water of 5 °C (from 14.6 to 19.6 °C, increasing the solubility of the oxygen from 10.2 to 8.2 mg.l^{-1}).

On the linear of the Allemette River downstream of ponds, the concentration of the oxygen decreases according to a regular gradient of 0.21 mg.l^{-1}

by 100 m on the first 3500 meters. The rate of saturation falls as for him quickly over the beginning of the linear, then according to a lower gradient farther downstream. This is because of the temperature which cools at first from upstream to downstream, causing an accumulation of the absolute decrease of the concentration and the relative decrease due to the increase of the solubility of the oxygen. Further downstream, when the stream ended its thermal adjustment in relation to the influence of the pond, the temperature increases again from upstream to downstream, so that the absolute decrease of the concentration in oxygen is offset by the relative increase due to the decrease of the solubility.

Other ponds were only followed on the short seasonal periods, essentially on a winter and a spring. The pond of Barres is a good example of water area which does not practically modify the oxygenation of the river. This one, the Petite Sauldre, possesses very high values as upstream as downstream, always close to the rate of saturation. From February to April, the rhythm of the oxygen values is identical upstream and downstream to the pond. However, in May, 2011, the concentrations in oxygen (average of 5 weekly data) are 8.54 $mg.l^{-1}$ in the river upstream to the water area and 6.89 $mg.l^{-1}$ downstream.

4. DISCUSSION AND CONCLUSIONS ABOUT WELL-EQUIPPED PONDS IN A CONTEXT OF HEADWATERS

In a classic way, for the entire hydrographic network blending river sections and ponds, a seasonal difference takes place. During the wintry period, the river water, cold and stirred by a high flow, sees a strong incorporation of atmospheric oxygen and reaches its maximum of oxygenation (Angelier, 2000). But later in the season, especially at the end of spring, vegetal explosion gives their maximum of oxygenation to ponds, by photosynthetic production. We so recognize the river sectors upstream of ponds and those of downstream which are influenced by water area, where the maximum of oxygenation is moved towards the warm season. The entire hydrographic network studied here enters certainly more or less in this general pattern; the highest concentrations in oxygen (and more still the relative saturations) were measured in spring in the surface water of ponds and in the river sections just downstream to them and under their influence. However, ponds studied here also present some peculiarities which distinguish them and make their even more interesting case.

The chain of two ponds of Moulin and Rochegaudon blocks a hydrographic basin of low slope; characteristic of the contact in glacis between Massif Central and Paris Basin. In the absence of pond, the water of the river system is little stirred; the current is very slow, even during the wintry and spring season of high-water. In summer, the flow is highly reduced and the creek (0 Strahler rank upstream of ponds) usually dries out naturally from July till September upstream to the chain of ponds. During a few weeks preceding the drying out, the water flows with difficulty between pools, where it stagnates rather. It results from it a rather warm and little oxygenated water. The head of basin presents moreover a wooded landscape dominated by the breeding activity, which rejects a certain quantity of nutriments. The basin in upstream to ponds suffers from eutrophication and the creek has difficulty to build an environment which would be favorable to the decomposition of organic matters. In these river conditions, ponds are favorable to the oxygenation of the small river.

But the configuration and the equipments of the chain of two ponds of Moulin and Rochegaudon add the conditions even more favorable to the oxygenation of the creek. The diversion which by-passes the pond of the Moulin short-circuits the initial curvatures of the channel and shortens the river linear before the elbow operated to return under the dam. On this section, the speed of the current is increased. Our measures show systematically concentrations in oxygen slightly more raised in the diversion than in the upstream river. The exit of water by monk of the pond of Moulin, which draws a mixture of waters of various depths, presents concentrations always superior to those of surface water of the pond but generally more low than that of the upstream creek. Thus, the water which enters in the pond of Rochegaudon, which is a mixture of the water of the diversion and the water of the monk of the pond of the Moulin (to which is added the water of an overflow of surface working at winter and the beginning of spring), is almost always higher than that of the upstream creek. On average of all the data, the water which enters in the second pond has a concentration of 0.87 $mg.l^{-1}$ higher than the one which enters in the first pond.

The originality of the second pond that of Rochegaudon, is to have two systems of reoxygenation. It is at first about a monk working fact as a waterfall of several meters, then a small doorway of about fifteen centimeters blocking the stream a few meters away downstream to its exit. Because of these two equipments, the concentration in oxygen is, on average of all the data, 0.11 $mg.l^{-1}$ more raised at the exit of the pond of Rochegaudon than to its entrance, although the surface water of the pond of Rochegaudon is less rich on average in oxygen than that of the pond of Moulin.

Ponds studied in Sologne are less complex, because they do not group in chain and do not have any set very supplied with varied equipments. The pond of Barres rather tends to change nothing either, at the end of the spring, to lower the oxygenation of the river. We can interpret this fact at first by the high quality of the river water of the hydrographic network (“blue class”, “very good quality “, upstream of the pond), which can only be degraded by a contribution of stagnant water. The Strahler rank of this river is 4 or 5 according to the considerations of different brooks in the hydrographic networks; its important flow is without common relation with the headwaters of the previous example. In addition, the pond of Barres is located on the diversion itself, leaving the free river in its original stream. From upstream to downstream, the seasonal maximum of concentration in oxygen is the winter. It is about a river rhythm, denoting a low influence of the pond.

In conclusion, the monitoring for two years of the chain of the ponds of the Moulin and Rochegaudon, which allows a study on the long term, showed that, in the context of a stream few oxygenated at head of pond, the presence of equipped ponds (diversion and waterfalls of reoxygenation) increased clearly the oxygenation of the stream in all the seasons and more still in warm season. From upstream to downstream, the monitoring was realized on several kilometers of river linear. It shows that the gain of oxygen due to the pond lowers little according to the way of the creek towards downstream: the favorable influence of ponds is thus protected for a long time on the stream. However, the temperature increased by the pond falls quickly according to the downstream: the unfavorable effect of the pond is so lost at the end of only 2 km. Other ponds, studied over a less long period, without equipment of reoxygenation and situated themselves on the diversion, leaving free the initial river channel, have a clearly less favorable influence on the oxygenation, even lower this one.

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